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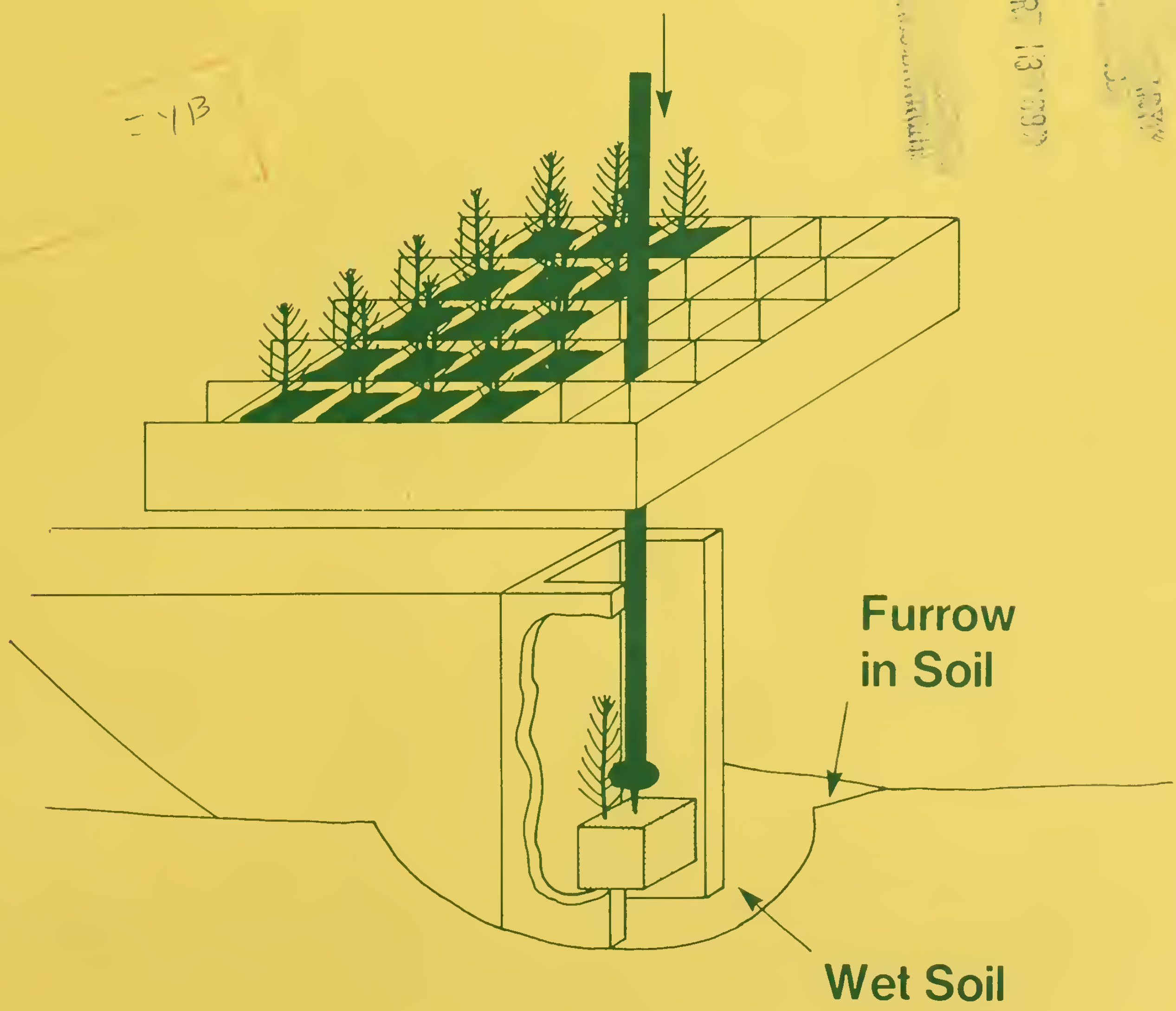
Proceedings, Combined Meeting of the Western Forest Nursery Associations:

Western Forest Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association

**August 8-11, 1988
Vernon, British Columbia**



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Abstract

This proceedings is a compilation of 42 articles on various aspects of forest nursery management in western North America. Specific topics include: seed, bareroot seedling culture, container seedling culture, nursery management, seedling quality, nursery pests, nursery equipment, and outplanting performance. Of particular note are articles on the new nursery technology of container-bareroot transplants.

Note

As part of the planning for this symposium, we decided to process and deliver these proceedings to the potential user as quickly as possible. To do this, we asked each author to assume full responsibility for submitting reviewed manuscripts in photoready format within tight deadlines. Thus, the manuscripts did not receive conventional Forest Service editorial processing, and consequently, you may find some typographical errors and slight differences in format. We feel quick publication of the proceedings is an essential part of the symposium concept and far outweighs these relatively minor distractions. The views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations or the USDA-Forest Service. Trade names are used for the information and convenience of the reader, and do not imply endorsement or preferential treatment by the sponsoring organizations or the USDA-Forest Service.

On the cover: One step in the transplanting of "miniplugs" — small container seedlings that are started in the greenhouse and then transplanted to bareroot nursery beds (see Hee and others, p. 168)

USDA Forest Service
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December, 1988

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Technical Coordinator:

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Rocky Mountain Forest and Range
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Contents

Outplanting Performance

Opening Remarks[1] √

Peter Ackhurst[2]

Good morning Ladies and Gentlemen.

I appreciate the opportunity to take part in the combined meeting of these two organizations, whose work is so important. As nurserymen, you play a crucial role in the reforestation process, which is essential to the future of forest management.

To those of you from other Regions of Canada, the United States and elsewhere, I would like to welcome you to British Columbia. While your agenda over the next three days is a busy one, I trust you will be able to enjoy Vernon and the Okanagan Valley.

Before going any further, I would like to make a few comments for the benefit of any of you not familiar with the forestry and nursery situation in British Columbia. We have 54 million hectares (134 million acres) of forest land in British Columbia and 95 percent of that 54 million hectares is still publicly owned by the people of British Columbia. The Federal Government has one percent of the forest land holdings and the private sector has the remaining four percent. In the past the cost of reforestation on Crown land, including the cost of seed and seedlings, was typically paid by the Crown in the past through credits to stumpage.

The Forest Act was amended on December 17, 1987, to state explicitly that basic silviculture is the duty of both the Crown and the forest industry. The amendments are based on the principle that the process and cost of reforestation are responsibilities which are directly related to the privilege of harvesting timber from Crown land. Fully productive forests in the future are the aim of a newly strengthened commitment to reforestation.

Basic silviculture ensures the establishment of a free growing crop of commercially valuable trees. Detailed requirements for basic silviculture will be enforced with new regulations which apply to both government and industry.

The government's funding requirements for basic silviculture will decrease as remaining obligations on past harvests are met. With the exception of some residual maintenance activities, all these remaining obligations will be addressed during the current five year program. Beyond this, the government's funding requirements for basic silviculture will depend primarily on fire and pest damage.

The cost of basic silviculture on Crown land harvested under the Small Business Forest Enterprise Program (SBFEP) will be covered by the price industry pays for the timber harvested. The government will continue to administer basic silviculture required under the program on behalf of small business operators.

The forest industry is responsible, as of October 1, 1987, for reforesting areas harvested under major licences. As mentioned previously, in the past, the cost of reforestation on Crown land, including the cost of seed and seedlings, was typically paid by the Crown through credits to stumpage. This cost is now borne fully by industry. The trees established on Crown land are the property of the Crown. The Ministry of Forests audits industry's silviculture performance and has authority to penalize licensees for non-compliance under the Forest Act and regulations.

Before harvesting timber under a major licence, the forest industry is now required to submit a pre-harvest silviculture prescription. This prescription must comply with the regulations under the Forest Act and be sufficient to ensure basic silviculture.

Our first forest nursery was established in 1927, but by 1938 only 526 hectares (1300 acres) had been planted, the program expanded during the war years and by the end of 1945 we were operating three nurseries. By 1976, in response, particularly from 1965, to pressure from the forest industry and the public, the reforestation program had expanded. Nine nurseries were now in operation, with the capability of producing in excess of 80 million bareroot seedlings and 20 million container seedlings.

In 1980 the government started a program of contracting out the growing of seedlings. The Ministry of Forests tree nurseries produced about 100 million seedlings in recent years, or

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[1]Opening remarks presented at the combined meeting of the Western Forest Nursery Council and the Forest Nursery Association of British Columbia, Vernon, B.C., August 8-11, 1988.

[2]Peter W. Ackhurst, Acting Director, Silviculture Branch, Ministry of Forests, Victoria, B.C.

about half of the provincial seedling requirements. Some of these nurseries have been instrumental in the development of techniques recognized world wide for their ability to grow superior seedlings. By 1987 some 40 nurseries, including 11 Ministry of Forests nurseries, were producing seedlings for reforestation in British Columbia.

In September, 1987 the government announced plans to sell nine of the eleven Ministry nurseries to the private sector, as part of the government's efforts to reduce direct involvement in the production and delivery of goods and services. In the private sector, the nurseries will have greater incentives and opportunities to expand their markets and develop further efficiencies.

At this time seven of the nine nurseries put up for sale have been sold or are in the final negotiation stage for turnover on September 1, 1988. Studies are now being carried out for disposition of the remaining two nurseries offered for sale.

The Surrey Nursery and the Skimikin Nursery near Salmon Arm will continue to be operated by the Ministry of Forests. These will enable the Ministry to continue experimenting with new nursery techniques, and to grow seedlings for SBFEP and areas denuded by fire and pests.

So much for the forestry and nursery situation in British Columbia.

This is the fourth time that the Western Forest Nursery Council is meeting in British Columbia. Previous meetings were held in 1952, 1962, and 1976. The Forest Nursery Association of British Columbia was organized in the early 80's. Many members of each organization have been attending each others meetings.

Looking over the agendas of past meetings held in British Columbia we find some of the same topics being discussed at all of the previous meetings. Cold storage is a subject which continually keeps appearing. Another subject that keeps repeating at meetings such as this is seedling quality and field results. Seedling quality is a decisive factor for the success of a plantation. There should be no need for, nor can we afford the cost of going back to, or back over an area, because of failure due to seedling quality.

Early in the century, Gifford Pinchot, predicting that the planting of forest tree seedlings would grow in importance, urged that forestry professionals accept the challenge of reforestation by learning not only where to plant but where not to plant, and how to select the right trees. I would not like to suggest that forestry professionals have not been doing that for some time, but let us say that they are starting to do it better. They have had to take up the challenge, if for no other reason than to offset increased costs.

At the time, Pinchot's emphasis on the need for foresters to know how to select the right tree probably referred to species selection but now, with the variety of stock types that we can produce, the designation of stock type is an equally important part of any planting prescription. The nursery has traditionally been the scapegoat for plantation failures but we are now getting evidence of the importance of proper selection of the stock type to survival and its physiological conditioning as well as careful planting.

Morphological characteristics of the stock, its height, root collar diameter, top/root ratio, root system, can largely be determined by the cultural practices at the nursery. That is how we have defined stock quality to date. Is it unfair to say that we have been content to ship out what our experience told us were nice looking tree seedlings? How often did we carry out the destructive sampling that is necessary if we are to be reasonably sure that those nice looking seedlings are not dead.

We know now that it is the seedling's potential for achieving a satisfactory growth rate that will determine the success or failure of plantations and it is not possible to make that judgement just from the appearance of the stock.

Besides destructive sampling to check on the quality of stock classified by its morphological characteristics, if we are to be able to satisfy the requirements of the foresters as they become more specific in their prescriptions, we will have to develop a better understanding of seedling physiological processes, particularly the induction of dormancy and the factors controlling the root regeneration process. Most nurseries today use cold storage units. This is a useful tool for balancing nursery workloads and is essential with the large nursery operations that have developed to secure the benefits of mechanization. To be used effectively however, we will have to be able to induce specific seedling physiological states prior to cold storage, such as root regeneration potential, and we have to be able to maintain physiological vigour during the storage process. There is still a lot of work to be done by the tree physiologists before we can feel secure.

We must be able to define quality standards on both a morphological and physiological basis.

The changes in the technology and economics of forest nursery operation and seedling production over the past decade exceed that of any previous period, and the pace of change appears to be accelerating.

Meetings such as this provide the opportunity for people from different regions to come together, to compare experiences and solutions of similar problems, to exchange information and ideas, and to consider new concepts.

In closing I would like to emphasize that your contributions as nurserymen are key to the future of forest productivity. Through application of your skills and dedication to the task of producing quality seedlings, coupled with tree improvement programs, and the tools of the silviculturist, we can expect the future forest resource to become increasingly productive on those areas that are intensively managed for timber production. In so doing, we can offset the inevitable loss of parts of the commercial forest land base to wilderness, environmental restrictions, urbanization, etc., and thereby fulfill society's increasing demand for the full range of forest resources.

Dormancy and Vigour of Tree Seeds[1]

C.L. Leadem[2]

Abstract. This paper discusses tree seed dormancy and vigour with specific references to the true firs (Abies). The benefits of a modified stratification method--the stratification-redry technique--are outlined. Physiological measurements are described with some examples of how they may be applied to assess seed vigour. Especially promising for the development of seed vigour indexes are low temperature stress tests, germination rates, seed respiration, and seed reserve levels. These may soon be employed as management tools to aid nurserymen to monitor the deterioration of seeds in storage, to assess the effectiveness of dormancy release treatments, and to predict seed performance in the nursery.

TREE SEED DORMANCY

As nurserymen, you probably recognize that the dormancy of tree seeds can be a major impediment to seedling production. Simply put, if seeds do not germinate, there will be no seedlings. Seed dormancy may be defined as:

"The inability of seeds, due to a mechanical or physiological block, to germinate even when placed under favourable conditions for germination."

In this context, the mechanical block is most often the seedcoat, whereas physiological blocks are generally biochemical. Most tree seeds are dormant, and therefore require special treatment before they will germinate. The most effective dormancy-breaking treatment for many tree seeds is the chilling of moist seeds at 2°C, otherwise known as stratification. A modified method of stratification, the stratification-redry technique (Danielson and Tanaka 1978, Edwards 1986), has been shown to be effective for very dormant seeds such as amabilis fir (Abies amabilis Edwards 1980a, 1981; Leadem 1986). In the past year, the stratification-redry procedure has also been successful in overcoming the dormancy of subalpine fir (Abies lasiocarpa) seeds (Leadem 1988).

The efficacy of the stratification-redry treatment was demonstrated in an experiment in which three different seed sources of A. lasiocarpa received 10 stratification treatments (table 1). In the first 6 treatments, moisture was not controlled during stratification. Seeds were imbibed for 48 h, and moisture content (m.c.) remained about 45% during the entire chilling period.

TABLE 1. STRATIFICATION TREATMENTS @ 2°C

No. Weeks	Wks @ 45% mc	Wks @ 35% mc	Total
1.	*	*	*
2.	4	-	4
3.	8	-	8
4.	12	-	12
5.	12	-	16
6.	24	-	24
	Stratification-redry treatments		
7.	4	4	8
8.	4	8	12
9. **	4	12	16
10.	4	20	24

* Seeds were imbibed for 48 h, but received no chilling.
** Standard stratification-redry procedure.

In the remaining 4 treatments, seed moisture was reduced to 35% m.c. for part of the stratification period. The stratification-redry procedure (Treatment 9, table 1) was the standard on which all moisture-control treatments

1 This paper was presented to the Combined Western Forestry Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association Meeting; 1988 August 8-11, Vernon, British Columbia.

2 Carole Leadem is a Plant Physiologist with the British Columbia Ministry of Forests Research Laboratory, 1320 Glyn Rd., Victoria, B.C., Canada V8Z 3A6

were patterned. In treatment 9 seeds were soaked for 48 h and stratified at 2°C for 4 weeks at 45 % m.c. Seeds were then dried to 35% m.c. and stratified for an additional 12 weeks. In the remaining treatments (7, 8, and 10), the number of weeks of moisture control are longer or shorter than in treatment 9.

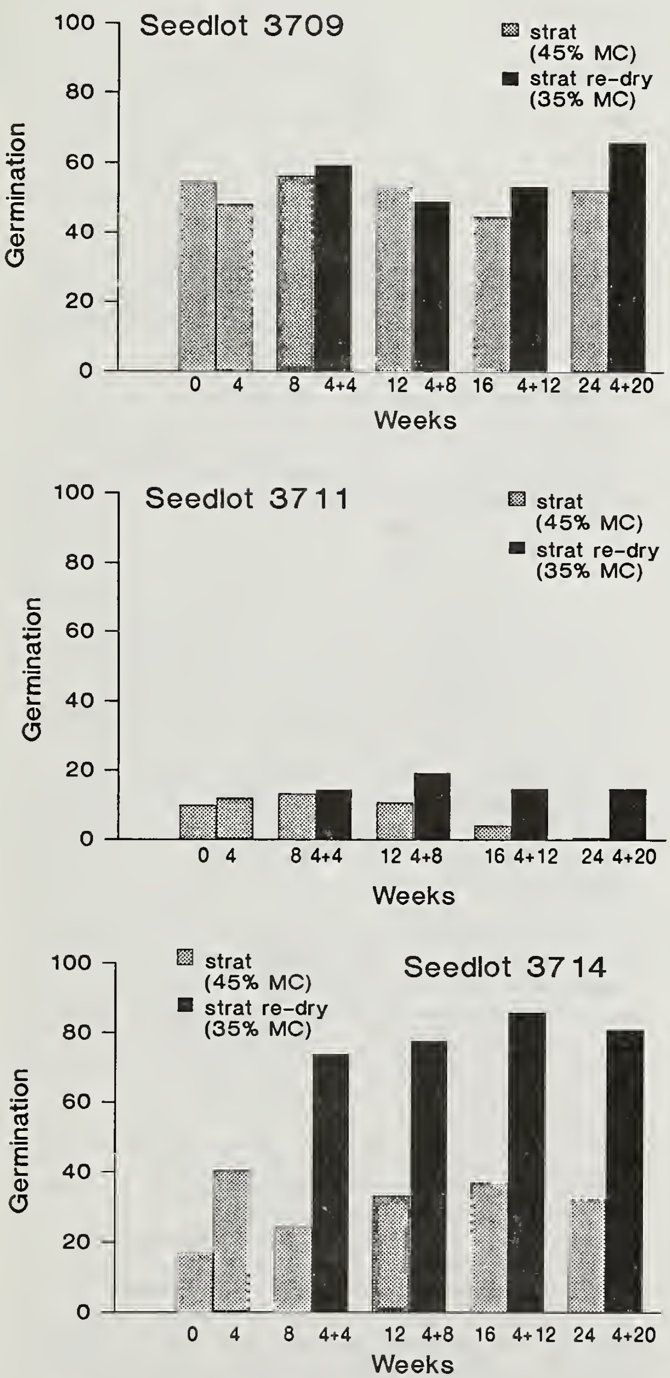


FIGURE 1. Germination of three Abies lasiocarpa seed sources to duration and stratification treatment with and without moisture control.

Germination tests of treated seeds were conducted by incubating the seeds under a daily alternating 30°C/20°C for 4 weeks (ISTA 1985). Eight hours of light were given during the high temperature period.

The responses of three A. lasiocarpa seed sources to stratification with and without moisture control are shown in figure 1. Lot 3709 exhibited the response of a nondormant seed source. Seeds germinated about 55% with no chilling, and none of the stratification treatments appeared to substantially increase germination above that of unstratified seeds. Although moisture control during stratification did not increase germination, the stratification-redry treatments were not detrimental to the germination of this nondormant lot. This is an important consideration in any nursery situation where efficient management is essential. Because the stratification-redry procedure enhances the performance of dormant seed sources but does not adversely affect nondormant seeds, only a single method is necessary to prepare seeds for sowing.

Seedlot 3711 consisted of poor quality seeds that did not respond very well to any of the treatments. This behaviour is characteristic of seeds that have been harvested prematurely or improperly handled in the field. These seeds do not germinate well, and deteriorate rapidly in storage (Edwards 1980). The quality of such seeds cannot be improved, regardless of treatment, and the best solution is usually to dispose of the lot.

In seedlot 3714, only 18% germination was achieved with unchilled seeds, but 4 weeks stratification substantially increased germination. This definite response to stratification is typical of dormant seed sources. Moisture control (i.e., reducing seed m.c. to 35%) during stratification had a major effect on germination of seedlot 3714. All the stratification-redry treatments (4 + 4, 8, 10 or 12 wks) significantly improved germination compared to that of seeds stratified for the same length of time without moisture control. The maximum response was 86% germination, observed in seeds which received treatment 9 (4 + 12 weeks). Seeds with no moisture control, and stratified for the same length of time, germinated only 37%.

Radicle emergence is generally taken as evidence of the breaking of dormancy, but more than just radicle emergence is necessary to demonstrate that dormancy requirements have been satisfied. Dormancy release is, in actuality, a composite of a number of qualities which enhance seed performance. In this regard, the stratification redry treatment effectively breaks dormancy of true firs (Abies), and also has been shown to enhance a number of qualities not ordinarily associated with the breaking of dormancy. Abies seeds are often susceptible to mold (Leadem 1986) and are poorly geotrophic. When given stratification-redry treatment,

however, the seeds not only germinate more rapidly and exhibit less fungal contamination, but the radicles are more likely to grow directly down into the substrate (unpublished data).

To date, the stratification-redry treatment has been found to be effective for releasing dormancy of *Abies amabilis* (Pacific silver fir); *Abies grandis* (grand fir); *Abies lasiocarpa* (subalpine fir); and *Abies procera* (noble fir) (Edwards 1981, 1982; Tanaka and Edwards 1986; Leadem 1986, 1988). Unfortunately, the use of stratification-redry on other species has been limited (Danielson and Tanaka 1978).

TREE SEED VIGOUR

It is generally acknowledged that seed vigour declines more rapidly than germination (Heydecker 1969). Accordingly, vigour tests have been employed as more sensitive indicators of deterioration and other qualities not as easily detected in germination tests. While several definitions of seed vigour have been proposed (Assoc. Off. Seed Anal. 1983), the following working definition is preferred:

"Seed vigour is that property which enables seeds to germinate quickly under a wide range of conditions, and endows germinants with the ability to establish quickly and resist disease."

This definition of vigour emphasizes the broader, more practical aspects of biological function as it relates to the health and performance of young germinants in the nursery. The period of early germination and emergence is critical to successful nursery production. Germinants which are endowed with those qualities referred to as vigour are better able to overcome the hazards inherent in the susceptible early emergence phase, and thus are more likely to become successfully established as healthy, free-growing seedlings.

Measurement of seed vigour

Although most nurserymen intuitively recognize vigour in seeds, the concept of vigour has been difficult to express quantitatively. The inability to quantify vigour has been a major obstacle to widespread acceptance of the seed vigour concept. However, some examples of previous attempts to quantify seed vigour are given in table 2. Germination value (G.V.) is a well-known measure devised by Czabator (1962) in which total germination and the speed of germination are combined into a single value. The G.V. index has only had limited use, however, because standard values must be empirically determined for each species. Germination value is expressed as a single value without units, and thus is also difficult to relate to other measures of germination performance.

TABLE 2. SOME INDEXES OF SEED VIGOUR

Index	Description
Germination value	Speed X total germination (Czabator 1962)
Stress tests	Temperature extremes (AOSA 1983)
Growth models	Mathematical expression (Tipton 1984)
Respiration	Biological function Carver and Matthews 1975)
Seed Reserves	Storage protein, lipids

Several seed vigour indexes, however, may have potential for testing tree seeds. Stress tests, usually conducted under high or low temperatures, have been widely used to test the vigour of agricultural species (AOSA 1983), and could be extended to tree seeds. Other examples of measures used to assess seed vigour are growth models (Tipton 1984), seed respiration (Carver and Matthews 1975) and seed reserves. Forest tree seed vigour based on low temperature stress tests, growth models, respiration, and seed storage products are considered more fully in the following sections.

Low temperature stress tests

Standard conditions have been prescribed for testing the germination of tree seeds (AOSA 1978, ISTA 1985). Although standard tests are essential when making comparisons between several seed lots, and between laboratories, the results of such tests may not be relevant to the nursery situation, because tests conducted under optimum conditions do not necessarily reflect how seeds will perform under less than optimal circumstances in the nursery.

Another consideration is that the benefits of seed treatments may not be apparent when comparisons are made under optimal conditions. Nursery tests conducted on *Abies procera* (Rehd.) by Y. Tanaka (personal communication, 1982) showed little difference between the stratification-redry technique and 2 months stratification when seeds were sown under warm conditions, but during cold, wet conditions, seeds that received the redry treatment germinated significantly better. Data obtained for *Abies amabilis* incubated under low temperatures (15°C/10°C) also illustrates that tests conducted under stress conditions may better indicate the efficacy of different stratification treatments in situations that are more similar to those encountered in the nursery (fig. 2). Similar data were obtained by Davidson *et al.* (1985) who also incubated *Abies* seeds under low temperatures.

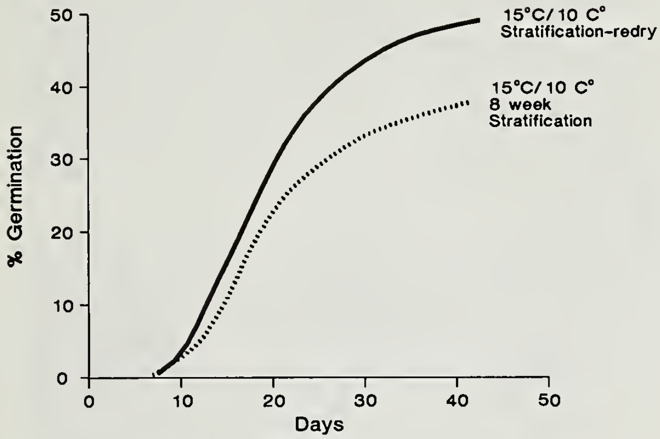


FIGURE 2. Germination of Abies amabilis seeds at low temperatures after receiving different stratification treatments

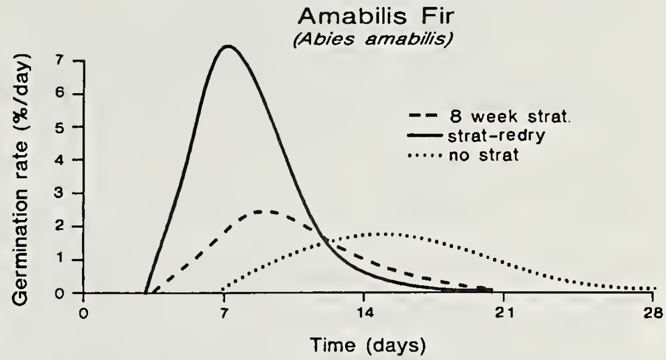


FIGURE 3. Germination rate curves of Abies amabilis seeds which received different stratification treatments.

Growth Model Vigour Index

Mathematical expressions of growth known as growth models, can be employed to transform standard germination curves into a more useful form (Tipton 1984). Growth models use the same basic data used to generate standard germination curves, but the data are mathematically transformed to create other expressions of biological performance, such as germination rate curves. Such curves graphically depict growth characteristics that are not otherwise detectable, and thus may be more sensitive indicators of seed performance (fig. 3).

The benefits of the stratification-redry treatment, for example, are readily seen if germination data is transformed and graphically expressed in the form of germination rate curves. After examining the curve characteristics of the three treatments, it is apparent that seeds given stratification-redry treatment begin germination earlier, that more germinants emerge each day, and that the germination is completed within a shorter period. By this means it is possible to describe those desirable, although generally subjective, attributes which are collectively known as vigour (table 3).

TABLE 3. CHARACTERISTICS OF VIGOUROUS SEEDS

Vigourous seeds have the ability to:

- germinate under a wide range of temperatures
- resist disease
- germinate rapidly
- establish quickly
- function with greater physiological efficiency

Levels of Seed Reserves

Since the germinating embryos are solely dependent upon seed reserves, the absolute amounts of reserves stored in the seeds might be expected to directly affect seed vigour. Conifer seeds store reserves mostly in form of fats and protein (Kozlowski 1971, Leadem 1987). With this thought in mind, the relationship between storage proteins and the seed quality was examined in Abies lasiocarpa to see if this could be developed into a useful indicator of seed vigour.

Seeds were sampled from three seed sources at various times during stratification. Seedcoats were removed and fresh weights were measured prior to grinding each sample in 0.05 M potassium phosphate buffer, pH 7.0. Ground samples were then frozen at -20°C until protein extractions, based on procedures previously described by Gifford et al. (1982), were performed. Protein content was assayed by the Lowry method (Lowry et al. 1951).

Germination tests were conducted at 30°C/20°C with 8 h light. Significant differences between protein concentrations and germination percent were tested using analysis of variance. The results are given in table 4.

For any one seedlot, protein values did not vary significantly during stratification. Significant differences in the total seed protein levels between the three seedlots were found ($F=23.39$, $P<0.001$). A direct relationship could also be seen between total protein and germination percentage; the greater the total protein values, the better the seeds germinated. These results are preliminary, but are encouraging to the extent that a vigour index based on protein reserves might exist. Ultimately, it may be possible to find specific proteins whose presence is highly correlated with seed vigour and quality, but further studies are necessary to determine the identity of the candidate proteins.

TABLE 4. TOTAL PROTEIN

Seedlot	Total Protein (mg /10 seeds)	Germination (%) (4wk @45% + 12wk@35%)
3714	26.16 a	86.0 a
3709	23.98 b	53.3 b
3711	18.56 c	14.7 c

Within each column, means with the same letter are not significantly different at p = 0.05 based on Duncan's Multiple Range Test.

Respiration as a Vigour Index

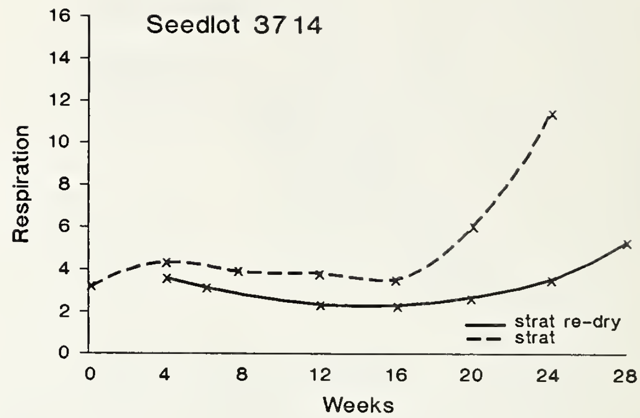
Seeds generate energy for growth and development by respiring stored reserves. The rate at which seeds use their reserves is an indication of their physiological efficiency, and, potentially, also a measure of vigour.

Seed respiration is easily monitored with an apparatus known as the Clark oxygen electrode (Yellow Spring Instruments, Yellow Springs, Ohio) (Murphy and Noland 1982). Seeds are placed in the cuvette with a phosphate buffer to retain peak physiological activity. Temperature is maintained at 30°C with the constant temperature water bath assembly.

Using the Clark oxygen electrode, the respiration of A. lasiocarpa seeds was monitored while applying the stratification treatments described in table 1. The primary objective of the experiment was to study the effects of stratification, both with and without moisture control, on seed respiration and germination.

Respiration of seeds of seedlot 3714, which had been previously demonstrated to be a good quality, but dormant lot, was low when seed moisture was controlled throughout the chilling period (stratification-redry treatment)(fig. 4). For seeds stratified at high moisture levels (> 45% m.c.), respiration rates were also initially low, but they increased exponentially after 16 weeks. In seeds stratified with moisture control (35% m.c.), respiration increased only slightly with treatments longer than 16 weeks.

A different respiratory pattern was observed in the poor germinating seeds of lot 3711. Although respiration rates were relatively low for the first 4 weeks, seeds stratified at high moisture contents exhibited excessive respiration when the treatment continued past 4 weeks. By comparison, respiration in seeds with moisture control remained comparatively constant and increased relatively little during stratification.



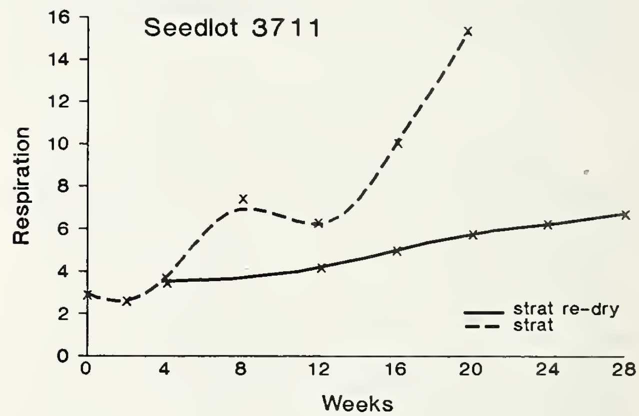


FIGURE 4. Changes in the respiration rates of Abies lasiocarpa seeds during stratification. Seeds were stratified at 2°C with or without moisture control.

It should be cautioned that respiration measured at 30°C does not necessarily reflect how seeds respond during stratification at 2°C, and also that, to date, few comparisons have been made. However, the data suggest a relationship between respiration and seed performance which may partly explain how the statification-redry treatment improves seed performance. Dormant species such as the true firs require long periods stratification to achieve optimal performance (Leadem 1986). The data in this study indicate that if seed moisture is kept at high levels, respiration tends to rise with increasing time of chilling at 2°C. Increased respiration during stratification may have significant impacts upon subsequent seed performance, for if reserves are respired during stratification, they will not be available for use during germination. If, on the other hand, stored products are slowly respired during stratification, more energy supplies will be available for the critical emergence and establishment period.

This study also indicates that changes in seed respiration may reflect changes in dormancy status. If respiration rates in figure 4 are compared to germination data in figure 1, it can be seen that the rise in respiration after 16 weeks is coincident with the length of stratification necessary to overcome the dormancy of the seedlot. This rise in respiration may be related to the breaking of seed dormancy.

The ability to identify when the breaking of dormancy occurs could prove to be valuable in assessing the physiological status of seeds. The usual method of determining stratification requirements is to subject seeds to a series of chilling times, and then germinate the seeds. The use of seed respiration as an alternate method of assessing performance would greatly simplify the search for optimal stratification treatments, since with the Clark oxygen electrode, seed respiration can be measured in 5 minutes as opposed to the 3-4 weeks required for a germination test.

CONCLUSION

Seed vigour has been shown to be related to germination rate, seed protein levels, and seed respiration, each of which have potential for the development of quantifiable indexes of seed vigour. Some day, we may have a simple, one-step vigour test which, by monitoring essential biological processes, will enable us to use our seed resources more efficiently. Physiological measurements such as seed respiration and storage protein may provide some valuable new technology for predicting seed performance, and to a time when nursery managers can truly say that "What you see, is what you get".

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Province of British Columbia Ministry of Forests Seed Centre[1]

R. Bowden-Green[2]

Abstract. The purpose of this poster is to outline the Ministry of Forests Seed Centre's services and facilities. We now offer our services on a fee for service basis and indicate the time lines required, procedures to follow and forms to use.

LOCATION

The Seed Centre, Ministry of Forests is located at 18793-32nd Avenue, Surrey, B.C.

CONE PROCESSING

The Seed Centre can store more than 6500 sacks (2600 hl.) of cones in storage racks.

An additional 1100 hectolitres of cones can be stored on conditioning trays in a temperature controlled environment.

The natural gas fired, tray-style kiln equipped with a programmable controller can process up to 100 hl. of cones per day.

A Cone Collector's Report form (F.S. 721 or 721-A) plus a Cone-Seed Services form are required to initiate the processing of cones at the Seed Centre.

SEED PROCESSING

Seed processing is accomplished using a modern on-line system.

Seed is processed to remove wings, debris and empty seed.

The product of processing is 98 to 100% pure seed which is 100% potentially viable.

SEED REGISTRATION

Seed destined for crown land must be registered.

The Tree Seed Register and Inventory System provides reports on seed information and balance in store.

SEED TESTING

A representative sample from each seedlot is tested.

The seedlot quality in storage is monitored including periodic retesting.

SEED WITHDRAWAL SERVICES

Seed withdrawal is achieved via submission of a Sowing Request System form or a Seed Sale and Withdrawal form.

Sowing Request System provides calculations and reports.

SEED WITHDRAWAL TIME LINE

Working days required from time of request to seed being withdrawn and shipped:

Period	Sowing Request	Seed Sale/ Withdrawal
Nov. 1-Dec. 31	25 workdays	25+ workdays
Jan. 1-Apr. 30	20 workdays	25+ workdays
May 1 -Oct. 31	6 workdays	6 workdays

SEED STRATIFICATION TIME REQUIRED

Stratification (days)	Species
21	(Spruce (Douglas-fir (Western larch
28	(Western hemlock (Mountain hemlock (Lodgepole pine (Ponderosa pine (Grand fir
84	(Subalpine fir (Amabalis fir (Yellow cedar (White pine

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1 Poster presented at the Combined Meeting of the Western Forest Nursery Associations, Aug. 8-11, 1988, Vernon, British Columbia.

2 R. Bowden-Green is with the British Columbia Ministry of Forests, Surrey, British Columbia.

Macro and Micronutrient Programmes in B.C. Bareroot Nurseries[1]

John W. Maxwell[2]

Abstract.--In 1986 an intensive foliar analysis programme was introduced, subsequently, boron, copper, iron and zinc were often found to be low or deficient during the growing season and lift. The programme combined the introduction of micronutrient soil amendments and foliar sprays and has significantly improved stock quality.

INTRODUCTION

In British Columbia, there are eight bareroot nurseries; six ministry, one company and one private, located in various climatic zones. Over the years, the nutrient programmes and stock standards have changed quite dramatically with increased demands for larger and more suitable stock types. In 1986, frequent foliar nutrient analysis programmes were introduced. This has helped in modifying fertilizer schedules to suit the different stock standards.

SOIL NUTRIENT LEVELS

Soil types on the nurseries vary from coarse sands to clay loams. Fortunately, most of the nurseries with the heavier soils are no longer in bareroot production. The ministry bareroot nurseries are on a three year crop rotation, with two years of crops and one of fallow. No green manure or cover crops are grown, which results in good disease control but is a poor soil management practice. As a result, organic matter levels must be maintained by adding peat prior to seeding and transplanting. The addition of sawdust in the fall, to reduce frost heaving, also helps. Although these practices maintain the level of organic matter and keeps the cation exchange capacity (O.M.) (C.E.C.) at a satisfactory level, they do not improve the soil tilth in the same way that humus does.

Soil analysis was only done during the summer of the fallow year. The nutrient levels that were used (table 1) were a modification of those established for Douglas fir by van de Driesche (1969), and further adjustments were made for the various nurseries as and when required.

Table 1.--1988 Soil nutrient levels[1] used on B.C. Forest Service nurseries.

ph	% O.M.	% N Kjeldahl	P pm Bray 1	K	Ca	Mg	CEC
				m.e.q./100g		dry	soil
5.2 -5.8	3-8	0.20 -0.25	100 -250	0.20 -0.30	5.0 -8.0	<1.4	15 -20

[1]These levels were required prior to sowing or transplanting.

Macronutrient plant analysis was only carried out at the end of the growing season on specific 1-0 and the occasional 2-0 seedlots. The 2-0 fertilizer programmes were determined using the mineral nutrient ratios for seedling tissue established by Ingestad (1979).

The pH was maintained at a high level for forest nurseries, because the fertilizers used tended to be acidic. During the growing season, a pH of 4.4 was often found in the soils, which does effect the availability of some nutrients.

The nitrogen (N) levels, although of major importance, were disregarded when preparing the fertilizer programmes because of the numerous processes which affect N in the soils. This results in too much variation over short periods. Ammonium sulphate was the main N source, with ammonium nitrate being applied occasionally on 2-0 and transplants. The latter

[1] Paper presented at the Combined Meeting of the Western Forest Nursery Associations, Aug. 8-11, 1988, Vernon, British Columbia.

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caused a considerable amount of damping off in 1-0 stock.

Phosphorus (P) was maintained at a very high level because a slight reduction at the time of seeding considerably reduced the size of the 1-0 and 2-0 stock. There were also indications that under certain conditions high P was essential for the success of some plug transplants. These levels were of concern, as they do reduce the availability of zinc (Zn), copper (Cu) and iron (Fe) (Chapman 1966). Superphosphate, triple superphosphate, diammonium phosphate and monoammonium phosphate were the P fertilizers used. The amount of monoammonium phosphate applied prior to sowing was reduced by injecting or banding it below the seed drill, which also resulted in a considerably improved 1-0 stock quality.

Despite potassium (K) levels being satisfactory or high in some nursery soils, there was often some difficulty maintaining acceptable levels in the seedlings and transplants (van den Driessche 1977). This became more pronounced during root wrenching and undercutting. It appears that these two cultural practices, combined with frequent irrigation, reduce the plants' ability to take up K. This may be due to the soil pH, the reduced root area in contact with the soil, root form (Mengel and Kirby 1982) and leaching (Duryea and Landis 1984). Frequent applications of potassium sulphate are now being made at these stages of root culture. High K soil levels also tend to depress the uptake of magnesium (Mg).

Though calcium (Ca) is essential for good root and apical meristem development, there was always some concern about the effect it had on the soil pH. When necessary, Ca was applied as either limestone or dolomite, and the rates used depended on the pH.

In spite of applications of dolomite, potassium-magnesium sulphate and magnesium sulphate, magnesium tended to be low. High K and Ca soil levels may induce Mg deficiency symptoms. The increase in the K supply may reduce the Mg content in the foliage. It does not, however, affect the levels in the roots or fruit to the same extent, because high K promotes the translocation of Mg towards fruits and storage tissues (Mengel and Kirby 1982). The calcium-magnesium and potassium-magnesium relationships are very important nutrient interactions in the production of seedlings.

Sulphur (S) was not a problem in bareroot production because of the large amounts applied in the fertilizers.

All the macronutrients were broadcast and worked into the soil prior to bed shaping. Some P was also injected or banded under the seed drill at the time of sowing, in the spring. Top dressings of the fertilizers were carried out on all stock types when necessary during the spring, summer and fall.

FOLIAR ANALYSIS FOR MACRO AND MICRONUTRIENTS

Until recently, little attention was paid to the micronutrients because the analysis service was not readily available. Over the years, visual identification of deficiencies was made and later confirmed by an analysis; but there was no micronutrient analysis programme in place. The importance of complete foliar analysis programmes in forest nurseries are demonstrated by the example of boron (B) increasing the resistance of forest plants to frost, drought and disease (Baule and Fricker 1970).

In 1986, a new programme was established allowing the nurseries to carry out foliar analysis for macro and micronutrients during the growing season. This was a tremendous step forward, although acceptable levels had not yet been clearly defined. The nutrient requirements and levels in plants vary with the species (Ballard and Carter 1986) and type of culture (Landis 1985). The levels that are used for bareroot are not necessarily suitable for containers. This is because the nutrient availability varies considerably between mineral soils and organic mediums, and is also affected by soil temperatures. There were difficulties in deciding on acceptable levels for all species and stock types, because they vary throughout the plant at different stages of growth. The levels used are based on trials conducted at the test nursery near Victoria, and research carried out to determine the best seedlings based on morphological and nutritional standards. The currently recommended nutrient levels (table 2) are used for all species and stock types.

Table 2.-- 1988 Nutrient Levels

Element	Target %	Accepted Range %
Nitrogen	2.0	1.50-3.50
Phosphorus	0.25	0.20-0.40
Potassium	1.0	0.80-2.00
Calcium	0.35	0.20-1.00
Magnesium	0.15	0.12-0.30
Sulphur	10% of N level	Minimum 0.15
	ppm	ppm
Iron	100	80-600
Copper	8	4-20
Zinc	30	25-80
Manganese	100	80 and up
Boron	30	20-50

When necessary, large macronutrient applications were made during the late fall and early spring. In order to accommodate various climatic conditions, the late fall top dressings were carried out at just about freeze up in the interior. The early spring ones were carried out in late February or early March at the coast (Mengel and Kirby 1982). Micronutrients were sometimes applied as soil amendments with the macronutrients.

During the growing season, foliar applications of P, K, Ca, and Mg, and micronutrients were made when necessary. The rates that were used (table 3) are the lowest ones that have been used successfully in the vegetable industry (Knott 1966) and the bareroot forest nurseries in British Columbia.

Table 3.-- Nutrient Application Rates

Nutrient	Material and approx. analysis	Soil Applic. (kg/ha)	Foliar Applic. (kg/1100 L water/ha)
Boron	Solubor ($Ns_2B_4O_7 5H_2O$) 20.5% B.	5	1
Calcium	Limestone, dolomite, gypsum, superphosphate	-	-
	Calcium nitrate ($Ca[NO_3]_2, 2H_2$) 20% Ca.	-	5-10
Copper	Copper sulphate ($CuSO_4, 5H_2O$) 25.5% Cu.	25	2
Iron	Ferrous sulphate ($FeSO_4, 7H_2O$) 20% Fe.	10	2
Magnesium	Dolomite 20-45% Mg.	-	-
	Magnesium sulphate ($MgSO_4, 7H_2O$) 9.8% Mg.	150-200	10-15
Manganese	Manganese sulphate ($MnSO_4, 4H_2O$) 24.6% Mn.	20	20
Sulphur	Agricultural Sulphur	100-200	-
	Ammonium Sulphur	-	-
	Potassium	-	-
	sulphate and	-	-
	superphosphate.	-	-
Zinc	Zinc sulphate ($ZnSO_4, 7H_2O$) 22.7% Zn.	10	2

Nutrient deficiency symptoms were considerably reduced following the implementation of the foliar analysis programme. Samples were collected in the early spring and during the growing seasons at 4-6 week intervals until the fall. During that period, some variability existed due to the translocation of nutrients to various organs; however, appropriate adjustments were usually made during the current growing season.

Enough top material was collected to provide at least 5 grams dried weight of small seedlings or needles. The tissue was air or oven dried at 60^o C prior to shipping to the laboratory, and the results were usually available within three or four days. This allowed remedial action to be taken immediately.

Analysis indicated that P, K, Ca and Mg were sometimes low. While P tended to be deficient in 2-0 coastal Douglas fir and sometimes in lodgepole pine, 1.5-1.5 interior spruce and 2-0 coastal Douglas fir often suffered from K deficiency and occasionally there were problems at some nurseries with Ca and Mg.

Among micronutrients B, Cu, Fe, and Zn, were the main concerns. B and Zn deficiencies appeared to be involved in the multi bud and leader, rosette, and dominant bud failure in interior spruce (Ballard and Carter 1986). These problems were eliminated or considerably reduced following the introduction of the micronutrient analysis and spray programme. Normally, a single application was necessary, but sometimes additional treatments were required. In the past, many of these problems were blamed on stock type, weather and/or chemical damage.

Intensive production of bareroot is still dependent on sound management. This is done by using all available resources including foliar and soil analysis, because the climate, environment and other factors all have considerable effect on a crop.

CONCLUSION

In British Columbia, the bareroot nursery stock types have improved considerably in the past few years. One of the major reasons for this has been the approach to plant nutrition. The new plant analysis programme has helped to optimize the plant nutrient status of forest seedlings.

When necessary, the nutrient target levels for the various species and stock types will be updated so that the programme will achieve its potential.

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Nursery Practices, Seedling Sizes, and Field Performance[1]

William I. Stein[2]

Abstract.--Highlights are presented from a large cooperative study to determine the combined effects of nursery cultural practices on the initial size and subsequent field performance of 2+0 Douglas-fir seedlings. The study involved seven sources of stock produced in three different nurseries and field plantings made over 3 years on 28 sites in southwestern Oregon. Seedbed density had more effect on the size of seedlings produced and on subsequent 4-year field survival and growth than did variations in irrigation frequency or undercutting and wrenching.

INTRODUCTION

A large cooperative research endeavor to determine the combined effects of nursery cultural practices on the size and subsequent field performance of 2+0 Douglas-fir seedlings has been underway in southwestern Oregon for the last decade.[3] This short report provides nurserymen a preliminary synopsis of field results that, when fully analyzed, will be covered in one or more scientific articles.

OBJECTIVES

Nursery cultural practices used in the production of bareroot stock received renewed emphasis during the 1970's. Wrenching was given particular attention, but various studies were also made on the effects of seedbed density, undercutting, fertilization, and other practices. Much information was produced by these studies, but there remained important gaps in our understanding; namely, (1) There was conflicting evidence on the benefits of wrenching. (2) Most studies had measured the effects of varying a single practice at only one nursery. (3) The longer-term effects of nursery practices on seedling field performance were not known.

A multi-faceted study involving three nurseries, outplantings in 3 years, and subsequent field observations for 4 years was carried out to learn more about the combined effects of nursery practices. The first description of this study was reported at the Nursery Council's meeting in Eureka, California (Jaramillo 1978, Stein 1978), and completed results for one facet of the effort were reported at the Council's meeting in Coeur d'Alene, Idaho (Stein 1984, 1985).

METHODS

The general approach in this investigation was to subject Douglas-fir seedlings to different combinations of nursery cultural practices during their second year in the nursery, measure a sample of the seedlings produced, and subject other samples to greenhouse and outdoor performance tests. The key performance test involved planting rows of seedlings representing each treatment combination on contrasting forest sites. Over a 3-year period, trials were made with seedlings from seven seed sources grown in three nurseries and tested by identical methods.

In four trials, seedlings were produced in 18 combinations of three nursery practices--two moisture regimes, three levels of root disturbance, and three seedbed densities. In two additional trials, fertilization was also varied, and each nursery practice was applied at two levels--16 combinations. One trial had only nine treatment combinations--three levels of root disturbance and three seedbed densities.

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[1]Paper presented at the Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia and Intermountain Forest Nursery Association meeting; 1988 August 8-11; Vernon, British Columbia.

[2]William I. Stein is a Principal Plant Ecologist, USDA Forest Service, Pacific Northwest Research Station, Corvallis, Oreg.

[3]Cooperating organizations included the Roseburg District, USDI Bureau of Land Management; D.L. Phipps Nursery, State of Oregon; Wind River and Humboldt Nurseries, Siskiyou National Forest, and the Pacific Northwest Research Station, USDA Forest Service. Financial support for this research was provided by the USDI Bureau of Land Management and USDA Forest Service under the auspices of the Southwest Oregon Forestry Intensified Research (FIR) Program.

In each trial, treatment combinations were replicated three times on stock of the same seed source--in most instances, replications were made in seedbeds adjacent to each other. Every treatment combination was randomly assigned to a plot in each bed. Either in the fall of the first season or early spring of the second, all plots were thinned as specified to 10, 15, or 30 seedlings per square foot (108, 161, or 323/sq. m). Later in the spring, one-third of the plots were undercut at 6 inches (15 cm). Another third of the plots, as designated beforehand, was undercut and wrenched at 8-inch (20-cm) depth when seedlings were 8 inches (20 cm) tall, with wrenching repeated at 3-week intervals until September. The remaining third of the plots received the same undercut and wrenching treatment and, in addition, was vertically root-pruned on two sides every 6 weeks. In their second growing season, seedlings were irrigated often enough before June 15 to keep their moisture stress at dawn below 5 bars. In the following 2 months, seedlings in half the plots were allowed to reach stresses up to 12 bars before rewatering. In late summer and autumn, all seedlings were allowed to reach the higher stresses before rewatering.

Samples of seedlings from all treatments were collected in fall and winter for measurement of size and tests of performance, but only those lifted in winter were outplanted on forest sites. To achieve equal sorting of all treatments, only damaged seedlings and obvious runts were culled. Thus, some small-diameter or short seedlings that normally would be culled were included in the sets of sample seedlings.

Seedlings of a single seed source were planted on four clearcuts appropriate in location and elevation for the source. Planting sites were chosen to represent contrasting conditions--generally moderate to severe reforestation situations (fig. 1). Three blocks of test trees were planted on each site; each block contained one row of each treatment. Rows contained 20 trees each. Thus, each treatment combination was represented by 240 trees per seed source--12 rows in three replications at four locations. Trees planted in the third year were protected by plastic mesh tubing. Most outplanting sites were on Bureau of Land Management lands both east and west of Roseburg, Oregon.

Survival and total height of outplanted seedlings were obtained after the first, second, and fourth growing seasons. Also, the size attributes at outplanting were measured for seedlings from all treatment combinations. For purposes of this broad overview, an average was calculated for each irrigation, wrenching, and density level tested on the individual seed source. Treatment averages from all seed sources with the same treatment combinations were then summed and overall averages calculated. Six of the seven seed sources included comparison of two moisture levels, but only five included three levels of root disturbance and seedbed density.

RESULTS

Seedling Size

Seedlings tested for field performance were generally of medium length, sturdy, and well-balanced. Top lengths of seedlings averaged 10.1 inches (25.7 cm), and means ranged from 8.0 to 12.8 inches (20.4 to 32.5 cm) among the seven

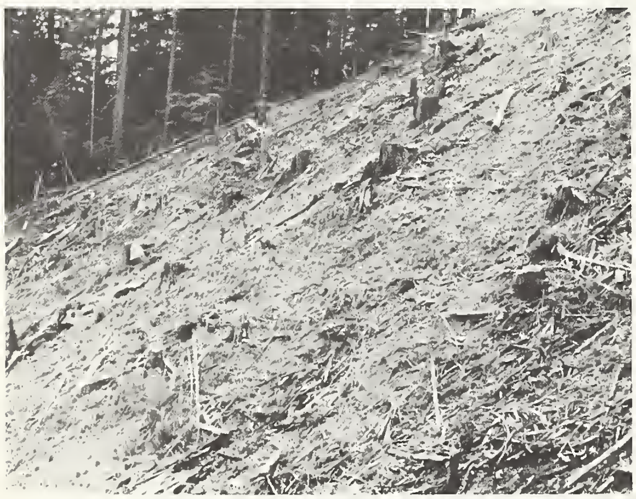

Figure 1.--Seedlings were planted on contrasting sites in geographic locations appropriate to the seed source. Sites included: (LEFT) a steep, unburned north slope at 2,800 feet (850 m) in the Cascade Mountains east of Sutherlin, Oregon, and (RIGHT) a freshly burned south slope reclaimed from evergreen brush at 1,700 feet (520 m) in the Siskiyou Mountains south of Riddle, Oregon.

seed sources. Stem diameters averaged 0.19 inches (4.9 mm), and source means ranged from 0.16 to 0.23 inches (4.0 to 5.9 mm). Total dry weights of seedlings averaged 7.4 gm, with source means ranging from 5.5 to 9.6 gm. Top-root ratios averaged 1.83 and ranged from 1.47 to 2.34 among the seed source means.

The combinations of cultural practices under which seedlings were produced influenced some of their physical attributes but had little influence on others. Additional irrigation produced seedlings that averaged 0.3 inch (0.8 cm) taller, the same diameter and weight, and slightly different in top-root ratio, 1.87 versus 1.80, than those irrigated with less frequency. Seedlings undercut and wrenched after reaching a specified target height averaged 0.4 inch (1.1 cm) taller than those undercut early in the season; their stem diameters averaged slightly less, however, 0.20 versus 0.21 inches (5.1 versus 5.3 mm). Average dry weight and top-root ratio were almost equal for seedlings subjected to undercutting, undercutting and wrenching, and undercutting and wrenching plus root pruning treatments.

Seedbed density had no effect on average top length of seedlings but influenced their average stem diameter and total dry weight. Among the seed sources tested at three densities, stem diameters averaged 0.23, 0.20, and 0.18 inches (5.7, 5.2, and 4.6 mm), respectively, for the least dense to the most dense seedbeds. Total dry weights averaged 9.2, 7.3, and 5.5 gm per seedling from the least dense to the most dense seedbeds, and top-root ratios were 1.73, 1.83, and 1.93.

Field Performance

Two-thirds of the seedlings planted in the field were alive at the end of 4 years. The average survival among the seven seed sources (and the different geographic areas they represented) ranged from 38 to 83 percent and among the 28 locations at which the seedlings were planted from 14 to 92 percent. Survival in midseason of the first year averaged 96 percent or more for all seed sources except one, demonstrating that healthy seedlings had been planted on all but the four locations receiving stock of this source. Midseason survival was 75 percent for the seed source affected by root rot in the nursery. This source also averaged the lowest survival by the fourth year (38 percent) and had the lowest average (14 percent) for any single field location. Low survival at another field location resulted from planting an area where grass and other competition was already established.

Variations in the cultural practices under which seedlings were produced had only minor influences on their field survival. Survival for seedlings produced under moderate moisture regimes averaged 4 percent higher than for those produced under abundant moisture regimes. Survival for seedlings that were only undercut averaged just 3 percent lower than those subjected to undercutting plus wrenching or wrenching and side pruning. Seedlings produced at the highest seedbed density averaged 6 percent lower survival than those produced at the lowest density.

Seedlings averaged 28.4 inches (72 cm) in total height 4 years after outplanting. As might be expected, there were large differences among sources (and the geographic areas they represented) in average total height--from 17.6 to 52.5 inches (45 to 133 cm). Among all 28 locations, average total height ranged from 11.7 to 63.9 inches (30 to 162 cm). There was as much as a two to one difference in total height among locations planted with seedlings of the same source. Heavy browsing by deer caused seedlings at one location to be substantially shorter than elsewhere.

Only the density at which seedlings were grown had a material effect on their total height in the field 4 years later. Average total height varied 0.4 inch (1 cm) or less for seedlings produced under the two moisture regimes or the three root disturbance treatments. Average total height was 1.8 inches (4.5 cm) greater for seedlings produced at the lowest seedbed density than for those produced at the highest density and intermediate for seedlings from medium density beds.

Stem diameters, measured at 12 inches (30 cm) above ground level, averaged nearly 0.4 inches (9.8 mm) 4 years after outplanting. There were large differences in average stem diameter among seed sources and the geographic areas they represented, ranging from 0.2 to 0.7 inches (5.6 to 18.4 mm). For individual locations, the range was even greater, from 0.15 to 0.88 inches (3.7 to 22.4 mm). Again, the cultural effect of seedbed density was more evident 4 years after outplanting than were the effects of moisture regime or level of root disturbance, but all treatment differences among average diameters were small, .04 inches (1 mm) or less.

DISCUSSION

The seedlings outplanted in this study varied substantially in size, but on the average, they met the quality standards considered desirable for Douglas-fir planting stock--top length over 8 inches (20 cm), stem diameter 0.12 inches (3 mm) or larger, and good balance between tops and roots. Top-root ratio was low, averaging 1.83 with a range of 1.31 to 2.43 among treatments. Wrenching regimes were timed to produce good-sized, balanced seedlings, and this objective was achieved. When outplanted, the primary physical differences among seedlings of different treatments were differences in stem diameter and weight attributable to the densities at which they were produced.

Four years after outplanting, differences in survival and growth of seedlings reflected

primarily the initial size effects attributable to seedbed density. Heavier seedlings, resulting from lower seedbed densities, tended to survive and grow better in the field. The effects reflect relatively small differences in density of the seedbeds--a target difference of 10, 15, and 30 seedlings per square foot (108, 161, or 323/sq. m) at the start of the second season. The lowest density at harvest was near 10 per square foot (108/sq. m) but actually closer to 25 than 30 per square foot (269 than 323/sq. m) at the highest density. Studies have shown that large seedlings do better than small seedlings on favorable sites, and within the limits of the seedling sizes tested, results of this study indicate that larger seedlings also tend to do better on sites where moisture stresses are moderate to severe.

Despite large differences in the climates and soils in which seedlings were produced and field tested, the same combinations of cultural practices had similar effects. This is an important finding for it improves the predictability of seedling performance--when seedlings treated the same way in different nurseries respond the same way, not necessarily in magnitude but in direction of the response. Among the range of cultural practices tested, evidence from this study indicates that seedbed density is a more critical determinant of seedling size and future performance than are more frequent watering or more root disturbance from wrenching.

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245

Effect of Paclobutrazol on Conifer Seedling Morphology and Field Performance[1]

W. Rietveld[2]

Abstract.--Paclobutrazol, an inhibitor of gibberellin biosynthesis, significantly reduced the growth of jack pine, red pine, and eastern larch bareroot nursery seedlings. Application in August prior to the final complete year in the nursery was more effective than application in April of the final complete year. In many cases, the higher concentrations of paclobutrazol (10-20 mg/plant) retarded root growth as well as shoot growth, and retarded first-year growth in the field. One treatment (red pine, 5 mg/tree, applied in April) resulted in a 20% reduction in seedling height, 33% increase in root dry weight, and 35% reduction in shoot:root ratio, without carryover effects to the field. Further work is needed to optimize the shoot and root growth responses to paclobutrazol and to control its persistence in the soil.

INTRODUCTION

Paclobutrazol[2] (PP333, ICI Americas, Goldsboro, NC) is a potent growth regulator of a broad range of angiosperms, including monocotyledons and dicotyledons, and herbaceous and woody species (Shearing and Batch, 1979, Quinlan, 1981, Williams and Edgerton 1983, DeJong and Doyle 1984, Wood 1984, Sterret 1985). An inhibitor of gibberellin biosynthesis (Hedden and Graebe 1985), paclobutrazol has been extensively studied in horticultural species because of its ability to retard vegetative growth while improving fruit set and yield. However, little work has been done on the effects of paclobutrazol on gymnosperms, particularly conifers. Wheeler (1987) reported that paclobutrazol significantly reduced the growth of container-grown Douglas-fir (Pseudotsuga menziesii Mirb. Franco) and loblolly pine (Pinus taeda L.) when applied as a soil drench to newly germinated seedlings, but did not affect growth when injected into 3- to 9-year old trees.

Paclobutrazol has several potentially important uses in forest tree nurseries. It (1) is an alternative to shoot pruning, (2) manipulates seedling size and proportions to meet specifications, (3) improves seedling adaptation to water stress by decreasing the shoot:root ratio, and (4) is a means to hold over unneeded stock an additional year. Realizing any of the benefits on this "wish list" depends on the effectiveness of paclobutrazol on a particular species, and on developing appropriate application rates and methods. This paper reports the results of a study of paclobutrazol applied to bareroot jack pine (Pinus banksiana Lamb.), red pine (Pinus resinosa Ait.), and eastern larch (Larix laricina (Du Roi) K. Koch) seedlings at different stages of growth.

METHODS

The study was conducted at the USDA Forest Service J.W. Toumey Forest Nursery at Watersmeet, MI. Jack pine was seedlot 0477, Nicolet National Forest, zone 4; red pine was seedlot 0009, Hiawatha National Forest, zone 6; and eastern larch was seedlot 0152, Ottawa National Forest, zone 5.

Six rates of paclobutrazol were applied to each species at two times in the cultural

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[2]Trade names are included for the information of the reader and do not constitute endorsement by the USDA Forest Service.

period (early versus late). Applications were made either in August prior to the final complete year in the nursery or in April of the final complete year. Figure 1 shows the treatment times. Existing beds of seedlings were used for the study. Each species and application time was a separate test. Plots were 30-cm (1-ft) sections of bed with 30-cm buffers between treatments and the three replications. Rates of paclobutrazol (50% wettable powder) applied were 0, 0.5, 1, 5, 10, and 20 mg active ingredient/seedling in 5 ml water. The total amount applied to each plot was based on average seedling density (100-125/lineal foot) for each species and bed. Solutions were applied to seedling foliage with a garden sprayer; the plots were isolated with panels during spraying. The beds were irrigated 24 hr after application to standardize uptake time. Thus, the treatments consisted of foliar plus soil application of paclobutrazol, as in normal practice.

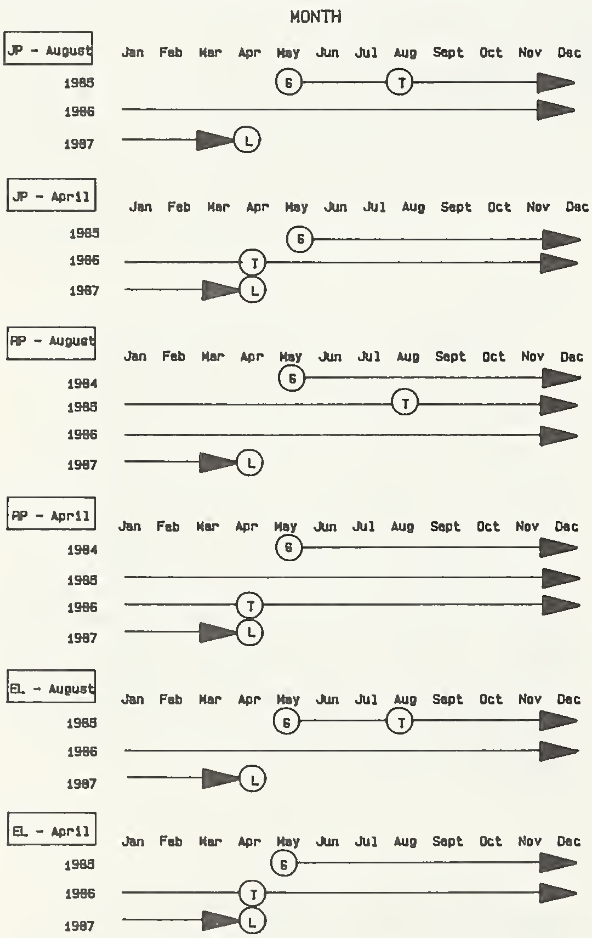

Figure 1.--Diagrams depicting growing periods and paclobutrazol application times for conifer nursery stock used in the study. Jack pine (JP) is normally grown to 2+0, red pine (RP) to 3+0, and eastern larch (EL) to 2+0. G = Germination, T = Treatment, and L = Lifting.

Seedling growth activity at time of application varied with age of plant. 2+0 and 3+0 jack pine and red pine had developing terminal buds at the August application, but 1+0 jack pine and 1+0 and 2+0 eastern larch were actively growing. The April application was made just prior to budburst for all species.

Seedlings were grown under normal nursery culture during the study. In April 1987 the seedlings were hand lifted and root pruned to a length of 20 cm. The three replications were combined, then a 15-seedling random sample was taken for morphology measurements, and a 30-seedling random sample was taken for a field test. Morphology measurements taken were: height, root collar caliper, root area index (using a Delta-T area meter), shoot dry weight, root dry weight, and shoot:root ratio (g/g). The field test consisted of three 10-seedling replications of each combination of species, application time, and chemical concentration planted under a rainshelter. Soil water potential was allowed to drop to -3.0 bars between irrigations. Survival, height growth, and caliper growth were measured at the end of one growing season.

Morphology data were analyzed for significant differences using one-way analysis of variance (ANOVA) and Tukey's multiple comparison test using a = 0.05. Field performance variables were analyzed using arcsin transformation, ANOVA, Tukey's test for survival data, analysis of covariance (using initial height and caliper as covariates), and Scheffe's multiple comparison test using a = 0.05 for height growth and caliper growth data.

RESULTS

Paclobutrazol treatments significantly affected all measures of growth and all species, primarily at the higher rates (table 1). In general: (1) order of sensitivity was eastern larch > jack pine > red pine; (2) application early in the culture period (August) was more effective than application late in the culture period (April); (3) the highest concentrations significantly reduced seedling size (height, caliper, shoot dry weight) and height growth in the field; and (4) effects on root growth were variable, but less than effects on shoot growth. Specific responses are presented by species and application time, focusing on significant differences from the control (0 mg/tree) treatment.

Jack pine--August application.--High concentrations of paclobutrazol effectively reduced overall seedling size. The 20 mg/tree concentration reduced height 54%, caliper 42%, shoot dry weight 48%, and root dry weight 46%. Height growth in the field test was also reduced 47%.

Jack pine--April application.--Paclobutrazol treatments only affected height growth in the field test, e.g. a 27% reduction by the 20 mg/tree concentration.

Red pine--August application.--The 20 mg/tree concentration reduced height 27%, caliper 23%, root area index 12%, and shoot dry weight 26%.

Red pine--April application.--The 5 mg/tree concentration reduced height 20%, increased root area index 51%, increased root dry weight 33%, and reduced shoot:root ratio 35%. Height growth in the field was reduced 69% by the 20 mg/tree concentration.

Eastern larch--August application.--The response was similar to jack pine--August, but to a greater degree. The 20 mg/tree concentration reduced height 65%, caliper 39%, shoot dry weight 59%, shoot:root ratio 25%, survival 41%, height growth 56%, and caliper growth 52%.

Eastern larch--April.--The two highest concentrations reduced seedling height, 17% for the 20 mg/tree concentration.

DISCUSSION

Paclobutrazol is effective in controlling seedling growth of coniferous species. The results of this study generally agree with Wheeler's (1987) in that young seedlings were most responsive. However, in this study root growth was inhibited nearly as much as shoot growth. The most notable (and usable) exception occurred in April-treated 3-year-old red pines at the 5 mg/tree rate (table 1). This retarded-shoot-growth/stimulated-root-growth response occurred in only one species and application time; therefore, its validity should be evaluated in further testing. Other investigators have also noted that paclobutrazol can either increase (Atkinson and Crisp 1983) or decrease (Williamson et al. 1986) root growth. This variability may be due to the concentrations and methods of application used. Treatments that maximize the effects on shoot growth relative to root growth (i.e., foliar sprays) may result in increased root growth, whereas treatments that expose the roots to high concentrations of paclobutrazol may reduce both root and shoot growth.

It is uncertain whether the responses observed in roots of treated plants are a direct effect of paclobutrazol on root growth or an indirect effect resulting from shoot growth modification (such as a shift in resource allocation to the roots). Williamson et al. (1986) reported reductions in root growth of peach seedlings that received foliar treatments. If transport of the compound is primarily via the xylem (Lever et al. 1982), this would suggest an indirect effect on root growth by paclobutrazol.

In all species, application of paclobutrazol early in the cultural period generated a stronger response. Paclobutrazol is quite stable in the soil and is readily carried over in the field from one season to the next (Williams 1984), and accumulates in leaf tissues (Early and Martin 1988). Thus it seems reasonable to suggest that application late in the previous season (August) will allow greater uptake and will have a greater effect on growth the following season than application in April just prior to growth initiation.

Although paclobutrazol offers promise as a tool for manipulating conifer seedling growth in the nursery, the variable responses are discouraging. Moreover, the inhibitory effects on root growth in the nursery and persistent retardation of growth in the field are also unwanted. Controlling the degree and duration of paclobutrazol's effects is complicated by the influence of tree vigor (Tukey 1983), the method of application (Barrett and Bartuska 1982), its persistence in the soil (Williams 1982), and time of application (this paper). Future work should concentrate on (1) attaining the "optimum" response where shoot growth is retarded and root growth is stimulated, and (2) controlling the persistence of paclobutrazol in soil.

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Table 1.--Effect of paclobutrazol on morphology and field performance of jack pine, (JP), red pine, (RP), and Eastern larch (EL) seedlings. Morphology measurements are based on 15 seedlings, field responses are based on 30 seedlings.

			Morphology						Field performance		
Species	Appl time	Tmt. (mg/ plant)	Height (cm)	Caliper (mm)	Root area index	Shoot dry weight (g)	Root dry weight (g)	Shoot/ root (g/g)	Survival (%)	Height growth (cm)	Caliper growth (mm)
JP	Aug	0	29.4 a[1]	6.4 a	66.6	6.628 a	0.975 a	7.0	90.0	13.3 a	1.5
		0.5	25.8 ab	5.5 ab	73.5	5.362 ab	0.969 a	6.5	93.3	11.2 ab	1.5
		1.0	22.2 b	5.1 bc	64.3	4.730 bc	0.806 ab	7.2	96.7	11.2 ab	1.4
		5.0	15.3 c	4.3 cd	54.8	4.027 bc	0.600 ab	7.1	90.0	8.0 bc	1.3
		10.0	16.0 c	3.7 d	50.9	3.245 c	0.496 b	7.0	83.3	7.6 c	1.3
		20.0	13.6 c	3.7 d	50.9	3.045 c	0.527 b	6.7	100.0	7.0 c	1.3
JP	Apr	0	29.0	5.2	49.2	4.817	0.630	7.8	90.0	10.8 a	1.0
		0.5	30.3	5.9	71.4	6.646	0.869	7.9	73.3	10.8 a	1.1
		1.0	28.9	5.0	60.6	5.016	0.635	8.5	80.0	10.6 ab	0.7
		5.0	27.4	4.9	54.5	4.957	0.659	8.2	93.3	9.7 ab	0.9
		10.0	28.9	5.3	66.2	5.618	0.786	7.7	76.7	7.6 b	0.8
		20.0	27.0	5.6	71.6	6.435	0.933	7.4	100.0	7.9 b	0.9
RP	Aug	0	22.2 a	4.7 ab	47.1 ab	4.986 bc	0.640	8.8	43.3	5.4	0.8
		0.5	21.0 ab	4.3 abc	45.2 b	4.816 bc	0.515	9.8	56.7	5.2	0.8
		1.0	22.8 a	4.8 a	45.6 ab	5.967 a	0.574	11.0	60.0	4.0	0.8
		5.0	17.3 bc	3.8 c	49.1 ab	4.250 bc	0.450	10.9	33.3	3.2	0.6
		10.0	18.0 bc	3.9 bc	61.7 a	5.078 bc	0.704	7.7	40.0	3.9	0.7
		20.0	16.3 c	3.6 c	41.3 b	3.675 c	0.480	8.0	36.7	2.9	0.7
RP	Apr	0	24.8 a	5.0	47.4 b	6.778	0.781 ab	8.9 a	70.0	4.9 a	0.5
		0.5	22.5 ab	4.4	41.7 b	4.974	0.579 b	9.0 a	36.7	4.6 a	0.6
		1.0	21.9 ab	4.2	52.7 ab	5.730	0.568 b	10.4 a	26.7	3.4 ab	0.1
		5.0	19.8 b	5.1	71.5 a	5.892	1.041 a	5.8 b	56.7	4.2 a	0.3
		10.0	22.2 ab	4.6	50.6 b	6.299	0.688 ab	9.6 a	40.0	3.4 ab	0.1
		20.0	24.3 a	4.9	49.8 b	6.665	0.720 ab	9.7 a	43.3	1.5 b	0.1
EL	Aug	0	24.8 a	5.2 a	40.7	2.716 ab	1.253	2.4 ab	96.7 a	13.9 a	3.1 a
		0.5	26.4 a	5.7 a	43.8	3.367 a	1.409	2.5 ab	96.7 a	9.5 ab	2.6 ab
		1.0	26.3 a	5.2 a	39.3	2.635 ab	1.403	2.0 b	93.3 ab	12.5 a	3.1 a
		5.0	23.4 ab	5.3 a	43.0	3.362 a	1.154	3.1 a	96.7 a	10.5 ab	3.4 a
		10.0	13.2 bc	3.9 b	27.9	1.669 bc	1.207	2.1 b	90.0 ab	11.7 a	3.5 a
		20.0	8.6 c	3.2 b	28.5	1.108 c	0.661	1.8 b	56.7 b	6.1 b	1.5 b
EL	Apr	0	31.2 a	4.7	52.2	1.929	0.825	2.5	83.3	7.9	1.5
		0.5	26.4 ab	5.1	61.2	2.336	1.037	2.5	100.0	9.9	2.0
		1.0	28.7 ab	4.6	67.3	2.023	0.971	2.4	96.7	9.4	1.9
		5.0	28.8 ab	4.9	60.8	2.265	0.913	2.7	96.7	9.2	1.9
		10.0	25.6 b	5.0	57.5	2.387	1.030	2.5	96.7	9.6	2.0
		20.0	25.9 b	5.1	63.0	2.505	1.002	2.9	96.7	9.0	2.2

[1]Values within each group followed by the same letter are not significantly different at the 5% level. Groups without letters had no significant differences.

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Fixing the Edsel — Can Bareroot Stock Quality be Improved?[1]

David G. Simpson[2]

Abstract.--Bareroot stock quality and subsequent field survival and growth can be improved by: (1) - growing seedlings at wider spacings which results in increased dry weight, lower shoot/root ratio, larger root collar diameter and in some cases increased root growth capacity (RGC); (2) - root culturing (undercutting or root wrenching) which increases RGC; and (3) - nutrient loading with fall applications of nitrogen fertilizers which increases both RGC and field growth.

INTRODUCTION

A B.C. Ministry of Forests report (Errico and Pelchat 1984) which, by means of computer assisted linear programming, compared several nursery stock type options to produce interior spruce (Picea glauca and/or Picea engelmannii) planting stock suggested that if field performance was ignored, 85% of the spruce trees planted in BC should be produced as 2+0 bareroot stock. However, when field performance and increased morphologic standards were included in Errico and Pelchat's model, only 5% of spruce planting stock was to be produced as 2+0 bareroot stock. Poor field performance (survival) of the 2+0 bareroot stock was the reason the model projected such a radical shift in spruce stock types. Field performance, survival, and growth data are limited for most species planted in British Columbia. Collective opinion, however, seems in agreement that the 2+0 seedlings produced are not surviving in great enough numbers and those that survive often grow poorly.

There are two choices to resolve the preceding problem:

a) abandon bareroot 2+0 stock in favor of more successful stock types, or
b) adjust or modify the 2+0 bareroot stock cultural regime so that survival and growth is improved.

[1]Presented at the joint meeting of the Western Forest Nursery Council and the Forest Nursery Association of B.C., August 9-11, 1988, Vernon, B.C., Canada.

[2]The author is a Research Scientist with the British Columbia Ministry of Forests at Vernon, B.C.

To the recipient of nursery stock, the first option is the most obvious solution as he wants only a product that performs. However, if the field performance of the least cost stock type, the 2+0 bareroot seedling, can be improved by changing nursery cultural and field handling practices, the objective of obtaining the greatest number of surviving, "free-to-grow" seedlings at the least cost may be in reach.

This report has been prepared to present the results of several experiments conducted by the author since 1977 on various aspects of bareroot nursery culture. The common goal of all these experiments has been to improve the field performance of 2+0 bareroot planting stock by making relatively low cost changes to nursery cultural and handling practices. At the onset, 2+0 bareroot stock quality, or field performance potential, was considered to be so poor that any improvements made were certain to more than justify the research invested.

Within the bareroot seedlings' nursery environment, there are relatively few cultural factors which may be manipulated with great precision. Factors which may be controlled include: nursery location and soil, seedling espacement, root culturing, nutrients, irrigation, and lifting dates. The response, in terms of seedling field performance, to any specific cultural factor interacts somewhat with genotype and prior nursery culture. For this reason, a series of experiments were conducted with various species to investigate the separate effects of several nursery cultural factors on field performance. The combined effect of simultaneous changes to several cultural practices is best seen as the change in field performance of stock produce in past years relative to field performance of present day 2+0

planting stock planted on similar sites. Due to the scarcity of field performance data, quantitative comparison of past and present 2+0 stock is rarely possible. However, collective opinion would suggest that some field performance improvement has occurred, but certainly greater success must occur to attain the goal of least cost for surviving free to grow trees.

NURSERY LOCATION AND SOIL

Implementation of a root growth capacity (RGC) testing program in 1977 for testing of nursery stock at the B.C. Ministry of Forests' Red Rock (Prince George) and Skimikin (Salmon Arm) nurseries and casual observations of the relative field performance of stock from these two nurseries resulted in the perception that there were substantial and consistent stock quality differences between the two nurseries.

To determine to what extent "nursery" and "soil" affected stock quality and field performance, a reciprocal soil transfer experiment was undertaken. At each nursery, raised beds of each nursery's soil were established and along with a regular nursery bed, sown with lodgepole pine and interior spruce seed. Using similar fertilizer and root culturing regimes in all soil treatments, the seedlings were grown for 2 years. On Oct. 20 of the second growing season, the seedlings were handlifted and stored overwinter (ca. 6 mos.) at -2°C. In the spring (May), stored seedlings' RGC's were determined, and the seedlings were outplanted onto a forest site near Vernon, B.C.

First year field survival of the interior spruce was high (86 to 97%) and there were no significant ($p \leq 0.05$) nursery or soil effects. Lodgepole pine seedlings grown in raised nursery beds at Skimikin nursery had reduced survival, perhaps due to some unmeasured quality differences (fig. 1). Growth of surviving

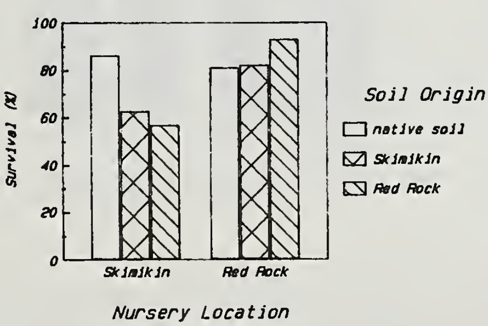

Figure 1.--First year field survival (%) of lodgepole pine grown at Skimikin and Red Rock nurseries in soil from those two nurseries.

seedlings was not affected by nursery soil and only slightly by nursery location (for example, fig. 2).

There were no consistent effects of either nursery or nursery soil on RGC after storage (fig. 3); however, it was noted that lodgepole pine RGC's were consistently greater than those of interior spruce.

The conclusion drawn from this experiment was that the previously observed RGC differences between Skimikin and Red Rock nurseries must have been due to some cultural factor rather than nursery climate, or nursery soil.

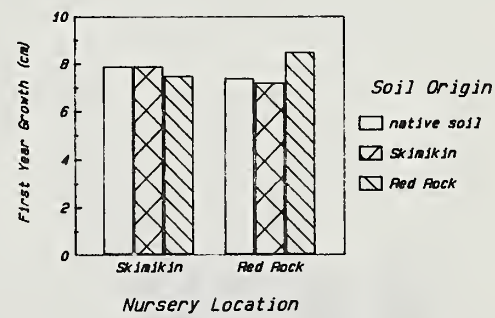

Figure 2.--Growth of surviving field planted lodgepole pine seedling grown at Skimikin and Red Rock nurseries in soil from those two nurseries.

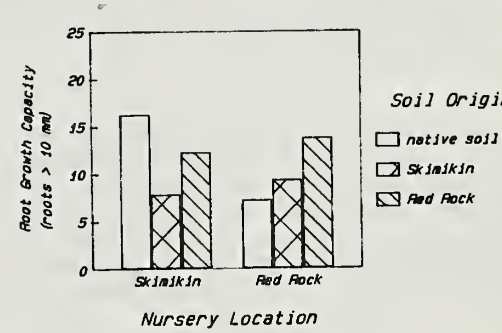

Figure 3.--Root growth capacity (RGC) of lodgepole pine grown at Skimikin and Red Rock nurseries in soil from those two nurseries.

SEEDBED DENSITY

Whether a stand of trees be in a nurserybed or on a forest site, competition occurs between individuals. In the bareroot nurserybed, conventional sowing machines scatter seed in six to eight parallel drill rows that are approximately 15 cm apart. The distribution of

seed within the drill rows is often not uniform resulting in clumps of seedlings. To demonstrate that field performance of Douglas-fir and ponderosa pine 2+0 planting stock could be improved by growing the seedlings at reduced and more uniform seedbed densities, two experiments were initiated.

In May 1978 plots with four seedbed density levels: 74, 118, 172, and 259 Douglas-fir seedlings per m^2, were established by thinning seedbeds sown to create an operational density of 259 seedlings per m^2. After two growing seasons the 2+0 seedlings were lifted and planted on a forest site. Survival of all treatments was near 100%, however, there were significant growth differences in both the first and second year after outplanting (fig. 4).

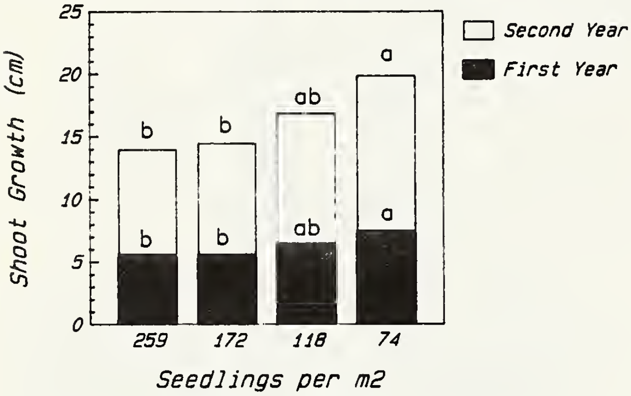

Figure 4.--Shoot growth (cm) of Douglas-fir seedling one and two years after planting on a forest site. For each year, means followed by a similar letter are not significantly different ($p \leq 0.05$).

The positive effect of reduced seedbed density on field performance was likely the result of larger seedlings being produced at the lower densities. While shoot height in the nursery was not affected by bed density reductions, both root collar diameter and seedling dry weight increased as density decreased (table 1).

Table 1.--Seedling spacing effects on Douglas-fir root collar diameter (mm), total dry weight (g) and shoot/root ratio. Means underlined by the same line are not significantly different ($p \leq 0.05$).

	Seedling Spacing (seedlings per m2)			
	259	172	118	74
Root Collar	3.5	4.5	4.9	5.8
Dry Weight	3.9	5.3	6.5	9.2
Shoot/Root	1.97	1.75	1.56	1.23

In 1979 a second experiment was established using ponderosa pine to investigate seedbed density levels of 80, 160, 240, and 290 seedlings per m^2. As in the earlier experiment with Douglas-fir, as ponderosa pine seedbed densities decreased; root collar diameters increased, seedling weights increased, and shoot:root ratios deceased (table 2).

Table 2.--Seedling spacing effects on ponderosa pine root collar diameter (mm), total dry weight (g) and shoot/root ratio. Means underlined by the same line are not significantly different ($p \leq 0.05$).

	Seedling Spacing (seedlings per m2)			
	290	240	160	80
Root Collar	4.2	5.1	5.2	6.3
Dry Weight	4.2	6.0	6.5	9.2
Shoot/Root	1.97	1.74	1.89	1.63

Significant positive improvements in both first year field survival and growth due to seedbed density reductions occurred when the ponderosa pine seedlings were planted on a forest site (fig. 5).

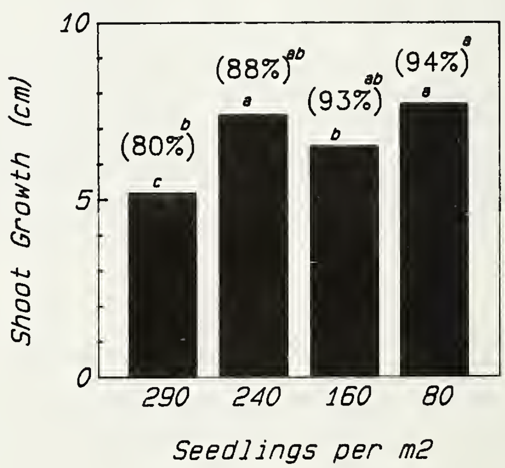

Figure 5.--Nursery bed spacing effects on first year survival (indicated in brackets) and shoot growth (bars) of outplanted seedlings. Means followed by similar letters are not significantly different ($p \leq 0.05$).

Often physical measures of nursery stock quality such as root collar diameters and shoot:root ratios are poor predictors of field performance because of variation in physiologic vigor or quality. Stored tissue nutrient levels and root growth capacity were measured to determine what seedbed density effects, if any, occurred. With Douglas-fir no significant differences in root growth capacity levels of seedlings raised at different seedbed density were observed, and of N, P, K, Ca, and Mg measured in root, stem and foliage tissue, only stem N levels were shown to increase as density decreased. This increase in stem N may reflect the proportionately greater amounts of bark and phloem tissue on the larger seedlings produced at low densities.

With ponderosa pine, tissue nutrient levels were not affected by seed bed density reductions. However, root growth capacity of seedling after over winter storage was higher in those seedlings grown at wider spacing (fig. 6).

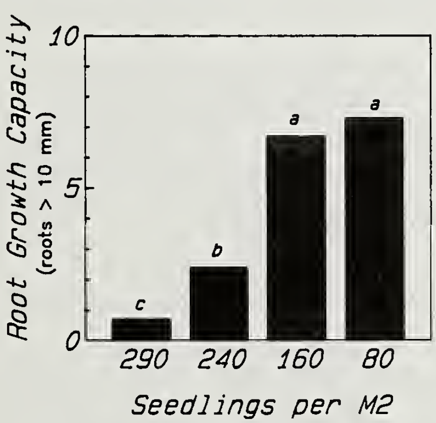

Figure 6.—Nurserybed spacing effects on root growth capacity (number of new roots longer than 10 mm per seedling) of ponderosa pine seedlings. Means followed by number letters are not significantly different ($p \leq 0.05$).

To summarize, in both experiments, seedlings produced at lower bed densities had better morphologic quality (greater dry weight; lower shoot:root ratio; larger root collar diameter) and in the case of ponderosa pine had improved root growth capacity levels. It is supposed that improvements to both morphologic and physiologic quality contributed to the superior field performance of the seedlings raised at lower densities.

ROOT CULTURING

Left undisturbed in the nursery bed, conifer seedlings produce a root system with long primary and secondary roots. This type of root system is well suited to exploitation of moisture and nutrients in the natural environment. However, if seedlings with a natural type root system are lifted, many of the second and higher order lateral roots necessary for new root regeneration on replanting are lost. A bareroot seedling for field planting must therefore be encouraged to develop a compact root system that will not be lost on lifting. Root culturing is used to produce compact fibrous root systems. There are three main root culturing practices: lateral root cutting, undercutting, and root wrenching.

Root pruning, as opposed to root cutting, refers to trimming of seedlings' root systems that may occur after the seedlings have been lifted from the nursery bed.

Lateral root cutting is accomplished by passing vertical blades or rolling coulters between the drill rows. This treatment is usually done during the second growing season, and promotes a bi-lateral shaped root system and tends to reduce the amount of root tearing which occurs during lifting and grading. Undercutting is done by passing a reciprocating horizontal blade through the seedbed to sever the primary and secondary roots at a depth of between 10 and 20 cm. In the late 1970's there were two main types of equipment used in B.C. forest nurseries: a "Marsh" undercutter having a fairly thick (5 mm) rigid blade that reciprocates fairly slowly, and a second, more recently introduced machine, the "Lotus" undercutter having a thin (2 mm) spring steel blade that reciprocates somewhat quicker. The Lotus machine makes a cleaner cut through the seedlings' root systems resulting in less bed disturbance such that a more shallow undercutting treatment is possible. The Marsh machine, by virtue of its more robust construction can travel through the seedbed at somewhat greater speeds.

Root wrenching is done using a non-reciprocating blade that is passed under the seedbed at an angle. This treatment results in a loosening of the bed, the degree dependent on the blades angle and speed through the seedbed. Root wrenching is usuálly done in the second growing season and often at a slightly greater depth than undercutting.

The effectiveness of root culturing, in particular, of undercutting and root wrenching, in promoting a more compact root system varies with species and nursery soil as well as severity, timing and frequency of treatment. To investigate the effectiveness of undercutting and wrenching in improving field performance potential, two experiments were conducted at the B.C. Ministry of Forests' Surrey, Skimikin, and Red Rock nurseries. The first experiment manually simulated shallow undercutting and root wrenching at weekly intervals from late July until mid-October of the 2+0 stock's second growing season.

There were no consistent effects on seedling height, root collar diameter or shoot and root dry weights which would be attributed to the undercutting and wrenching treatments. However, root systems of seedlings receiving undercutting or wrenching treatments were noted to be more compact and fibrous than were the root systems of seedlings receiving no root culturing.

Seedlings produced in this experiment were not field planted, however, root growth capacity measurements made in the spring after 24-weeks of -2°C cold storage suggests that the undercutting and wrenching treatments in some cases significantly increased this indicator of field performance potential (fig. 7).

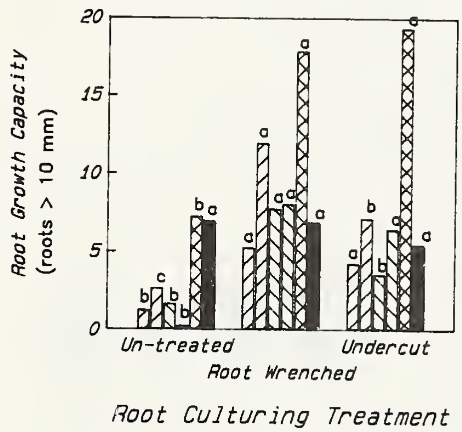

Figure 7.--Root culturing effects on root growth capacity (number of new roots longer than 10 mm per plant) of white spruce (right hatch), Engelmann spruce (left hatch), lodgepole pine (cross hatch) and Douglas-fir (solid). Within each species, means followed by similar letters are not significantly different ($p \leq 0.05$).

Except in Douglas-fir, the effects of the root wrenching treatment on post-storage root growth capacity was equal to or better than the undercutting treatment.

The manual root wrenching treatment used in this experiment was more severe, and at a shallower depth than the machine root wrenching usually practiced in British Columbia nurseries. A second experiment to determine if similar results could be obtained using a standard wrenching bar for the root wrenching and the thin blade "Lotus" undercutter was conducted at the B.C. Ministry of Forests' Skimikin Nursery beginning in 1981.

The results from this experiment (fig. 8) suggests that root wrenching (RW) resulted in slightly shorter seedlings, but that the field growth of these seedlings was similar to seedlings receiving the undercut (U) treatment.

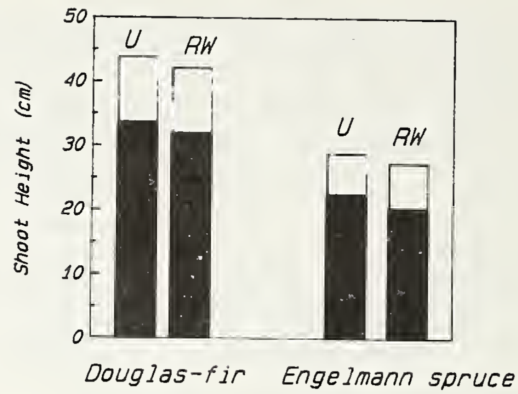

Figure 8.--Root culturing effects on average height of seedlings in the nursery (solid bar) and after one year on a forest planting site (open bar). U= undercut only; RW= root wrenched.

The conclusion drawn from these root culturing experiments is that as field performance of root wrenched and undercut seedlings seems to be similar, and likely better than non-root cultured seedlings, that the choice of root culturing method should be based on operational preference.

NUTRIENT LOADING OR FALL FERTILIZATION

Moisture stress and reduced fertilization are often used in forest nurseries to slow shoot growth, induce dormancy, and promote cold hardening of conifer nursery stock (Burdett and Simpson 1984). These practices can contribute to reduced tissue nutrient levels. Several authors (Anderson and Gessel 1966; Benzian *et al.* 1974; van den Driessche 1984) have reported improved field performance attributable to fall fertilization. Earlier experiments in B.C. nurseries (Donald and Simpson 1985) found that fall fertilization of seedlings with a balanced fertilizer (4-12-8) improved both root growth capacity and first year growth after outplanting.

To separate the effects of nitrogen (N), phosphorus (P), and potassium (K) on RGC and performance of outplanted stock, an experiment was undertaken at two interior nurseries (Red Rock near Prince George, B.C. and Skimikin near Salmon Arm, B.C.) and one coastal nursery (Surrey near Vancouver, B.C.). Four species were treated: white spruce ; Engelmann spruce ; lodgepole pine ; and interior Douglas-fir . Fifteen fertilizer treatments were applied to 2+0 bareroot seedlings 6 to 8 weeks before their being lifted to overwinter cold (-2°C) storage.

Root growth capacity was measured after a storage period of approximately 6 months (October-November to early May) and outplantings

were established in irrigated but not fertilized transplant beds at Skimikin nursery. Significant RGC improvements in spruce from both Red Rock and Skimikin nurseries occurred only in those fertilizer treatments containing N (fig. 9). The RGC response was greater in Skimikin-grown stock than in Red Rock-grown stock and may be related to the higher N-uptake. Spruce stock which received N at a rate of 500 kg/ha 34-0-0 had foliage N levels increased from a level of 1.9% to 3.1% at Skimikin nursery and 1.5% to 2.0% at Red Rock nursery. Spruce stock treated at Surrey Nursery failed to show a RGC improvement, perhaps because little uptake of N was observed.

Lodgepole pine from Red Rock nursery regenerated large numbers of roots in all treatments, and there were significant RGC improvements in those fertilizer treatments containing N. Douglas-fir at Skimikin Nursery responded similarly, having higher RGP levels in those treatments containing N (fig. 9).

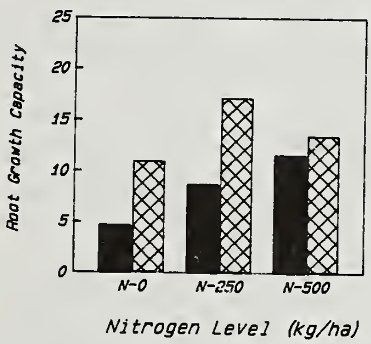

Figure 9.--Nutrient loading effects on root growth capacity (number of new roots longer than 10 mm per plant) of interior spruce (solid bar) and Douglas-fir (cross hatch bar). Means indicated are pooled values for treatments at Skimikin nursery where nitrogen (as 34-0-0) was applied at 0, 250, or 500 kg/ha.

Phosphorus applied singly, or in combination with other nutrients as top dressings was not taken up by any of the species, and there were no treatment effects on RGP or growth after outplanting. Potassium content was only slightly increased by fall applications of K; however, it was noted that N application decreased foliar K levels.

First year growth responses after outplanting were similar (fig. 10) to the RGC responses to fall fertilization treatment wherein those treatments containing N resulted in improved shoot growth.

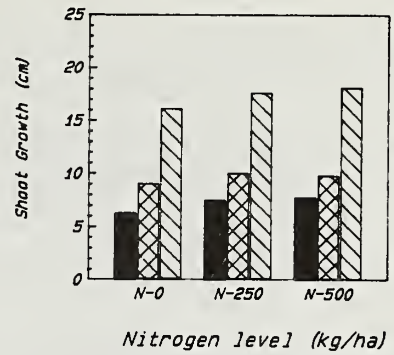

Figure 10.--Nutrient loading effects on root growth capacity (number of new roots longer than 10 mm per plant) of interior spruce (solid bar), Douglas-fir (cross hatch), and lodgepole pine (right hatch). Means indicated are pooled values for treatments at Skimikin and Red Rock nurseries where nitrogen (34-0-0) was applied at 0, 250, or 500 kg/ha.

In summary, significant positive improvements in post-storage RGC and subsequent field performance of 2+0 bareroot spruce, Douglas-fir and lodgepole pine nursery stock at interior nurseries should be expected with addition of N as 34-0-0 at rates of 250-500 kg/ha 6 to 8 weeks prior to lifting to overwinter (ca. 6- to 8-month) storage at -2°C. Spruce at coastal nurseries, such as Surrey, are not expected to respond to late season fertilizations as undertaken in this experiment.

OPERATIONAL TRIAL

Once it had been established that substantial improvements to bareroot nursery stock quality could be obtained by bed density reduction, root culturing, and nutrient loading, an operational demonstration of the combined effectiveness of these practices was undertaken.

The demonstration consisted of six 120 m long seedbeds sown with interior Douglas-fir, lodgepole pine, and white spruce. These beds were divided in half with the first 60 m of each bed receiving "normal" nursery culture (circa 1980-81) and the second 60 m receiving "improved" culture.

Seedbed density was reduced about one-half (table 3). Root culturing in the "improved culture" consisted of fortnightly wrenching at 15 cm depth from July 15-Sept. 30, while root culturing in the normal culture area was done much less frequently (exact details not available). Fall fertilization was applied as a single application of 34-0-0 fertilizer at

250 kg/ha on Sept. 1, which was 6 weeks prior to lifting. With the exception of the single fall fertilization, both normal and improved seedbeds received identical fertilizer applications.

First year field performance of the spruce was not measured; however, one Douglas-fir seedlot was outplanted as were two lodgepole pine seedlots. The results from these plantings (fig. 11) suggest that the seedlings grown with the improved cultural practice had significantly better first year field performance.

Table 3.--Operational demonstration.

Factor	*Normal Culture*	*Improved Culture*
Bed Density	180–360	115–130
Root Culture	occasionally	fortnightly
Nutrient Loading	none	250 (34-0-0)

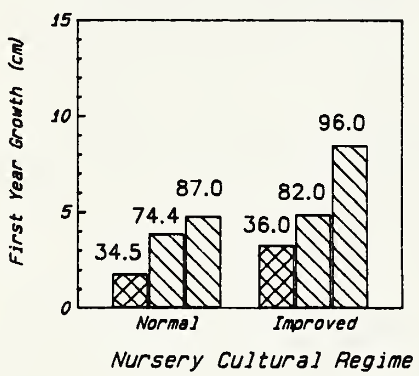

Figure 11.--First year survival (%) and growth (cm) of Douglas-fir (cross hatch) and lodgepole pine (right hatch) which received "normal" and "improved" nursery cultural regimes.

CONCLUSION

The data obtained in the preceding experiments suggests that there is potential to improve the field performance of 2+0 bareroot seedling for use in reforestation through relatively low cost changes to the nursery cultural practices used to grow this stock type. The economic efficiency of this stock type suggests it should receive serious consideration as a reforestation alternative.

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ACKNOWLEDGEMENTS

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Effect of Controlled-Release Fertilizers on Formation of Mycorrhizae and Growth of Container-Grown Engelmann Spruce[1]

Gary A. Hunt[2]

SUMMARY

Two controlled-release NPK formulations (Osmocote and Nutricote) and one micronutrient formulation (Micromax) were added as supplements to a soluble fertilizer regime and evaluated for their effects on seedling growth and development of naturally occurring mycorrhizae in 1-0 container-grown seedlings of *Picea engelmannii* Parry. Treatments were (all received identical amounts of soluble fertilizer): 1) Osmocote, 2) Nutricote, 3) Osmocote + Micromax, 4) Nutricote + Micromax, 5) Micromax, 6) soluble only. Seedlings supplemented with Osmocote or Nutricote had lower root weight, but greater shoot length, stem caliper and total weight compared to controls receiving only soluble fertilizer. Addition of Micromax did not alter growth compared to controls, but Micromax plus Osmocote decreased shoot length and shoot:root ratio compared to Osmocote alone; Micromax plus Nutricote increased shoot length compared to Nutricote alone. Seedlings receiving a supplement of Micromax alone or given only soluble fertilizer did not meet minimum standards for caliper or shoot length set by the B. C. Forest Service.

Five types of mycorrhizal fungi established naturally during the study. Feeder roots of treatments receiving Osmocote or Nutricote were predominantly colonized by *Thelephora terrestris* at percentages ranging from 72 to 97. This contrasted with nonsupplemented treatments where *Thelephora* was substantially reduced (mean of 38 percent colonization) and E-strain formed a major component of total colonization. Percentage of nonmycorrhizal feeder roots was highest when Osmocote was used (16 percent), but did not exceed six percent in other treatments. Osmocote was also detrimental to mycorrhizal diversity compared to nonsupplemented controls; one fungus was present with Osmocote (*Thelephora terrestris*) compared to four fungal types in nonsupplemented controls.

In two supplemental experiments, effects of different release rates (types) of Nutricote and two rates of one type were examined. Comparison of four types of Nutricote (70, 100, 140, and 180-day release rates) showed few effects of release rate on growth. Compared to the 100-day formulation, the 70-day formulation produced greater stem caliper. Seedlings receiving 70 or 140-day supplements had greater shoot:root ratio, and shoot length was approximately 3 cm greater than trees with 100 or 180-day supplements. Mycorrhizal colonization did not differ substantially among the types, although E-strain colonized at low levels (up to 11 percent) with Types 100 or 140 and was absent in the others.

In a comparison of two rates of Nutricote Type 70 (1.9 and 4.7 Kg m^{-3}), little effect on shoot growth was evident (dry weight of roots was higher and shoot:root ratio reduced at the lower rate), but fungal diversity and colonization by E-strain were decreased at the the higher rate.

Data comparing growth of seedlings predominantly colonized by E-strain or *Thelephora* demonstrated that E-strain significantly increased stem caliper, dry weight of roots, total seedling weight, and improved the Dixon Quality Index value.

When supplementing soluble fertilizers with controlled-release NPK formulations for optimizing seedling balance and root development, the rate of the supplement should be the minimum required for obtaining acceptable seedling size and tissue nutrient content.

A detailed report of this study is being prepared for journal publication.

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[1]Paper presented at the Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia and Intermountain Forest Nursery Association meeting; 1988 August 8-11; Vernon, British Columbia.

[2]Gary A. Hunt is Research Scientist, Balco Canfor Reforestation Centre Ltd., Kamloops, B. C.

Growth of Chemically Root-Pruned Seedlings in the Greenhouse and the Field[1]

David L. Wenny[2]

Abstract. -- Cupric carbonate treated containers produced ponderosa pine, western white pine and Douglas-fir seedlings with a more natural lateral root distribution than controls. Treatment has not increased survival or height growth after three field seasons.

INTRODUCTION

Root morphology differs between natural and container-grown seedlings. Natural seedlings generally develop a well distributed lateral root system providing mechanical stability and maximum growth potential (Stein 1978). Container-grown seedlings frequently have long lateral roots directed downward along the container wall until air-pruned at the drainage hole. In the field, such seedlings often have limited lateral root egress from upper portions of the plug but a high concentration of root egress from the plug base. Restricted root egress may reduce potential survival, growth, and mechanical stability, particularly on drier sites. Burdett (1978a,b) reported root elongation of container-grown lodgepole pine (Pinus contorta Dougl.) seedlings was completely inhibited upon contact with container walls coated with cupric carbonate. After outplanting, lateral roots of treated seedlings egressed from the upper portion of the root plug in a pattern similar to a natural root system (Burdett 1981; Burdett and others 1983). McDonald and others (1981) found similar results with ponderosa pine (Pinus ponderosa Laws. var. ponderosa Engelm.). Wenny and Woollen (1988) used this cupric carbonate technique for root pruning northern Idaho sources of western white pine (Pinus monticola Dougl.), ponderosa pine, and Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco) seedlings. We found a significant increase in root egress from the upper portions of the plug in growth room tests. First year field results of these seedlings did not increase significantly in growth or survival rates (Wenny and others 1988).

METHODS

Northern Idaho sources of Douglas-fir, ponderosa pine, and western white pine seedlings were chemically root-pruned while growing in the University of Idaho Research Nursery greenhouse. Two Ray Leach® pine cell trays (200 cells per tray) and two Styroblock 4A trays (198 cavities per tray) were used for each species. Forty pine cells per tray and 39 cells per styroblock (each 66 cm^3) were randomly assigned one of five treatments: an unpainted control; or a latex paint coating containing cupric carbonate at concentrations of 0, 30, 100 or 300 gL^{-1}. Since previous research with chemical root pruning by Burdett (1978) and McDonald (1981) found a concentration of 100 gL^{-1} $CuCO_3$ was effective in inhibiting root growth, the 30, 100, and 300 gL^{-1} concentrations were chosen in an attempt to bracket an optimal concentration for the species studied. Containers were filled with 1:1 peat:vermiculite forestry potting mix. Seeds were sown and the containers placed on greenhouse benches to receive species specific Research Nursery growing regimes (Wenny and Dumroese 1987a,b). Seedling height and root collar diameter measurements were taken at monthly intervals during the growing season. Data collected were subjected to conventional analyses of variance and Fisher's protected LSD.

Growth Room Tests

Dormant seedlings were removed from the containers (February), and placed into cold storage at 2°C. A root growth potential test (Duryea 1984) was initiated to evaluate effects of chemical root pruning on root system morphology. Ten seedlings from each container type and treatment combination were planted into 1-gallon pots containing 1:1 peat:vermiculite forestry potting mix. The potted seedlings were placed in a growth room following a split plot randomized complete block design. Growth room

[1]Paper presented at the combined meeting of the Western Forest Nursery Council, Forest Nursery Association of British Columbia and Intermountain Forest Nursery Association. Vernon, British Columbia. August 8-11, 1988.

[2]Idaho Forest, Wildlife and Range Experiment Station Contribution No. 403.

[3]David L. Wenny is Associate Professor of Regeneration and Manager Forest Research Nursery, University of Idaho, Moscow, Idaho.

temperatures were 27°C during the 16 hour day and 21°C at night. To obtain a 16 hour photoperiod, light energy reaching the canopy at an intensity of 220 $uEm^{-2}s^{-1}$ was provided by fourteen 96 inch Grow-Lux fluorescent bulbs. Root measurements were collected from three zones: top, middle, and bottom. New roots, longer than 1 cm, emerging from the plug were measured, counted and weighed for each separate zone. Root dry weights were obtained after oven drying at 60°C for 24 h. Seedling height, root collar diameter, shoot dry weight, the number, length, and dry weight of new roots by root zone, and total root length values were subjected to conventional analyses of variance and Fisher's protected LSD.

Field Tests

In April, seedlings were planted on the University of Idaho Experimental Forest. A randomized complete block design with three replicates was used. Ten seedlings of each species for each tray type and treatment combination were randomly assigned within a block. After the first growing season, survival, height, root collar diameter, shoot and root dry weights, and new root number were measured. Survival and growth data were collected after the second and third growing seasons. The plantation will be re-examined in the future.

RESULTS & DISCUSSION

Greenhouse and Growth Room

Shoot growth was uninfluenced by treatment during greenhouse culture. Height and root collar diameter measurements were not significantly different at any time during the growing season (April - October). Observation of root development showed nontreated seedlings had many more long, lateral roots running longitudinally along the plug wall, while treated seedlings had most lateral roots pruned at the plug wall.

Growth room data indicate seedling height, root collar diameter, and shoot dry weight was unaffected by treatment, regardless of species and container combinations. Root development did show a treatment affect with greater new root numbers, dry weights, and lengths in the top and middle plug zones of cupric carbonate treatments. These results were significant for most species and container combinations and are best illustrated by combining total new root length for the upper zones (Table 1). Increases in total length and total number of roots from chemical root pruning probably occurred because 1) primary, secondary, and tertiary chemically pruned lateral roots resumed growth from the upper portions of the root system after planting and 2) pruning enhanced initiation of higher order laterals. In contrast, unpruned seedlings, with primary and secondary lateral root tips at the plug bottom, lack this growth resumption in the upper portions of the root system. Although unpruned seedlings still initiate higher order laterals in the upper root plug, it is not at the enhanced rate of chemically pruned roots.

Field Performance

After one field season, all $CuCO_3$ treatments display a trend of greater new root numbers in

Table 1. Mean total root length (cm) in the top and middle root zones for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	730 BC	1304 AB	431 B	276 C	567 B	783 C
Paint	550 C	646 B	908 B	144 C	736 B	1137 C
30 gL^{-1}	739 BC	1610 AB	2292 A	1134 AB	1061 B	3088 A
100 gL^{-1}	1528 AB	2046 A	2347 A	1433 A	1306 B	2531 AB
300 gL^{-1}	2292 A	1628 AB	897 B	874 B	3782 A	1382 BC
LSD	800	1091	1352	520	1165	1250

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

the upper two-thirds of the plug for all species, but the difference is not significant for all container types (Table 2). A trend of reduced new root numbers in the lowest root zone occurs with $CuCO_3$ treatment, but is not significant with all tray types (Table 3). No trend appears when new root numbers throughout the plug are totaled (Table 4). This suggest cupric carbonate treatments did not increase the total number of new roots, but altered root distribution within the plug, increasing the proportion of roots in the upper two-thirds of the plug.

Examination of new root dry weights in the upper plug shows a general increase with a $CuCO_3$ treatment (Table 5). New root dry weights tend to decrease with treatment in the lowest root zone (Table 6). In neither case are differences significant with all species and tray type combinations. When root dry weight data is combined for all root zones (Table 7), no trend is apparent. Some seedlings had few new roots but their dry weights were high because of secondary, tertiary, and higher order lateral roots. Conversely, some seedlings had many new primary roots yielding low dry weights.

Seedling survival, height growth and root collar diameter after outplanting was unaffected by treatment during the first three years. Root redistribution, with greater numbers and lengths of new roots in the upper portions of the plug, did not result in seedling growth differences. Burdett (1981) also found seedling growth was not increased until after the third growing season when a 15% height increase was detected. Root egress on sampled seedlings did not differ between controls and treated seedlings for Douglas-fir. For pines, root egress was greater from the upper portions of the plug since the controls had more long laterals directed downward along the plug walls.

Management Implications

A planted seedling's root morphogenesis is dependent upon the elongation of existing roots and the initiation of new roots along the plug wall. Root elongation and initiation are influenced by 1) nursery cultural practices, 2) planting medium, and 3) planting tool. Our field results, to date, have not shown benefit from chemical root-pruning treatments. This may be due to the high degree of nontreated seedling root egress. In circumstances where cultural or handling/storage practices produce seedlings with excessive long lateral roots or media is compacted in the planting operation, chemical root-pruning may prove to have more immediate benefit.

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Table 2. Mean number of new roots (> 1 cm) in the top and middle root zones for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	20 A	16 BC	13 B	14 A	18 C	19 B
Paint	18 A	14 C	13 B	17 A	27 B	22 B
30 gL^{-1}	23 A	31 A	23 A	20 A	34 AB	35 A
100 gL^{-1}	21 A	27 AB	28 A	17 A	38 A	28 AB
300 gL^{-1}	26 A	27 AB	27 A	17 A	28 B	25 AB
LSD	NS	11	8	NS	8	12

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

Table 3. Mean number of new roots (> 1 cm) in the bottom root zone for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	30 A	16 A	16 A	15 A	24 A	17 A
Paint	16 B	12 AB	10 A	16 A	23 A	13 AB
30 gL^{-1}	12 B	15 AB	11 A	14 AB	13 AB	12 AB
100 gL^{-1}	7 B	7 B	11 A	7 B	24 A	10 AB
300 gL^{-1}	9 B	9 AB	10 A	12 AB	11 B	5 B
LSD	10	9	NS	7	11	8

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

Table 4. Mean number of new roots (> 1 cm) in all root zones for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	49 A	32 AB	29 AB	29 A	42 B	35 A
Paint	34 B	26 B	23 B	33 A	50 AB	35 A
30 gL^{-1}	35 AB	46 A	35 A	34 A	46 B	47 A
100 gL^{-1}	27 B	33 AB	39 A	24 A	61 A	38 A
300 gL^{-1}	35 AB	35 AB	36 A	29 A	40 B	31 A
LSD	15	17	11	NS	14	NS

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

Table 5. Mean new root dry weight (gm) in the top and middle root zones for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	0.43 B	0.40 B	0.31 B	0.37 A	0.77 A	0.92 B
Paint	0.38 B	0.47 AB	0.50 AB	0.41 A	0.97 A	1.00 B
30 gL^{-1}	0.73 A	0.85 A	0.80 A	0.56 A	1.29 A	1.47 A
100 gL^{-1}	0.52 AB	0.58 AB	0.69 AB	0.49 A	1.05 A	1.14 AB
300 gL^{-1}	0.61 AB	0.65 AB	0.72 AB	0.76 A	1.06 A	1.07 AB
LSD	0.27	0.38	0.43	NS	NS	0.46

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

Table 6. Mean new root dry weight (gm) in the bottom root zone for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	0.30 A	0.33 A	0.33 A	0.52 A	0.53 A	0.48 A
Paint	0.20 AB	0.26 AB	0.39 A	0.32 A	0.57 A	0.59 A
30 gL^{-1}	0.15 AB	0.28 AB	0.41 A	0.41 A	0.45 A	0.55 A
100 gL^{-1}	0.07 B	0.11 B	0.31 A	0.23 A	0.57 A	0.58 A
300 gL^{-1}	0.10 B	0.17 AB	0.12 A	0.50 A	0.41 A	0.30 A
LSD	0.16	0.20	NS	NS	NS	NS

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

Table 7. Mean new root dry weight (gm) in all root zones for Douglas-fir, ponderosa pine, and western white pine.

	SPECIES/CONTAINER					
	DOUGLAS-FIR		PONDEROSA PINE		W. WHITE PINE	
TREATMENT	Leach	Styro 4A	Leach	Styro 4A	Leach	Styro 4A
Control	0.73 A	0.73 AB	0.64 B	0.89 A	1.30 A	1.40 A
Paint	0.58 A	0.73 AB	0.87 AB	0.73 A	1.55 A	1.59 AB
30 gL^{-1}	0.88 A	1.13 A	1.21 A	0.97 A	1.74 A	2.01 A
100 gL^{-1}	0.61 A	0.69 B	1.00 AB	0.73 A	1.62 A	1.72 AB
300 gL^{-1}	0.71 A	0.83 AB	0.84 AB	1.23 A	1.47 A	1.37 B
LSD	NS	0.41	0.56	NS	NS	0.61

Means followed by the same letter were not significantly different when subjected to Fisher's LSD test at the alpha = 0.05 level.

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Effect of Nursery Culture on Morphological and Physiological Development of Western Hemlock Seedlings[1]

J.T. Arnott, B.G. Dunsworth, and C. O'Reilly[2]

Abstract.—Western hemlock seedlings were grown in two container sizes, subjected to short days and moderate moisture stress in July, lifted at three dates during the winter and cold stored for periods of up to four months. The influence of these cultural treatments on seedling morphology and physiology was measured. Short days effectively stopped shoot growth extension; moisture stress did not. Root growth capacity and dormancy release tests indicated a preference for lifting hemlock immediately before planting in mid-March, or after two months of cold storage from a mid-January lifting date.

INTRODUCTION

Variation in seedling survival and growth after outplanting reflects differences in the quality of the seedlings as they leave the nursery (Ritchie 1984). Quality is defined by certain morphological and physiological criteria and, because it is essential to successful plantation establishment, it has been the subject of considerable research and review (Bunting 1980; Duryea 1985; Ritchie 1984; Schmidt-Vogt 1981; Sutton 1979). Advances in nursery technology and containerized stock rearing (Scarratt et al. 1981; Tinus and McDonald 1979) provide many nurseries with the ability to grow a wide range of seedling types with different morphological and physiological characteristics. However, these seedling characteristics must be tailored for specific ecological conditions at the planting site and nursery growers must have the knowledge and experience to grow specific seedling stock types for a particular site.

A comprehensive study was made of the effects of nursery cultural regimes on the growth, development, morphology and physiology of container-grown western hemlock (Tsuga heterophylla (Raf.) Sarg.) seedlings. This paper reports the influence of container cavity size, dormancy induction regime, time of lift, and duration of cold storage on the morphology and physiology of the seedlings. Results of other aspects of the nursery experiment will be reported elsewhere (O'Reilly et al. 1989a, 1989b) while the early growth response of these different types of seedlings after outplanting will be reported by O'Reilly et al. (1989c) at this meeting.

MATERIALS AND METHODS

Western hemlock seeds (British Columbia Forest Service, Registered Seedlot No. 3097; Lat. 48°39'N, Long. 123°39'W; Elevation 760 m) from Vancouver Island were stratified at 2°C for four weeks before sowing February 12, 1986 in BC/CFS styroblocks (Beaver Plastics Ltd., Edmonton, Alberta)[3] of small (PSB 313[4] abbreviated to S3) and large (PSB 415B[4] abbreviated to S4) cavity diameters. The styroblocks were placed in an experimental greenhouse at the Pacific Forestry Center, Victoria, B.C. (Lat. 48°28'N) maintained at 21°/18°C (day/night), 50 % humidity and an 18-h photoperiod. Natural day length was supplemented by high pressure sodium vapour lights

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[3]Mention of specific commercial products and formulations does not constitute endorsement by the Canadian Forestry Service.

[4]PSB 313 and PSB 415B styroblocks have respective cavity diameters of 27 and 35 mm, ribbed cavity volumes of 57 and 102 cm^3 and spatial densities of 932 and 526 cavities·m^{-2}

that provided a photon flux density of at least 6 $\mu mol \cdot s^{-1} \cdot m^{-2}$ (500 lx) at the seedling level. The styroblocks contained a 3:1 mixture of peat and vermiculite with 2.0 $kg \cdot m^{-3}$ dolomite lime (10 mesh and finer) added. The styroblocks were misted daily during germination, and fertilized with biweekly applications of 20N-20P-20K fertilizer with micronutrients (Green Valley Fertilizer, Surrey, B.C.) at 500 $mg \cdot L^{-1}$ and every two weeks with the heptahydrate form of ferrous sulphate at 155 $mg \cdot L^{-1}$. After September 15, greenhouse temperatures were set a 18°/15°C (day/night) until September 29, 15°/10°C until October 27, 15°/5°C until November 17, and 10°/5°C, thereafter.

Dormancy Induction Treatments

The seedlings were subjected to four dormancy induction regimes; a long- or short-day photoperiod of 18 h and 8 h, respectively, under conditions of moderate moisture stress (dry) or no moisture stress conditions (wet). In this section we use the term dormancy to mean a suspension of shoot length growth without specifying the physiological state of the plant (Downs and Bevington 1981) or the stage of bud development (O'Reilly et al. 1989b). The objective of applying these dormancy induction regimes, and growing the seedlings in small and large containers, was to create a range of different morphological seedling types. Induction regimes began on July 15, 1986, five months after seeding, and ended four weeks later. Styroblocks in the moisture stress treatments were allowed to dry down to 2.8 (S3) and 3.1 (S4) kg below their saturated weight before re-watering to saturation with 20N-20P-20K fertilizer added. This dry-down was repeated three times during the four-week dormancy induction period. Predawn xylem water potentials of the seedlings before rewatering to saturation averaged -1.0 MPa. Seedlings in the no stress treatments received water and nutrients as described under materials and methods above. Following the dormancy induction treatments, the water-soluble fertilizer was changed to 10N-52P-17K (Green Valley Fertilizer) at 500 $mg \cdot L^{-1}$ and the seedlings were grown under the above-described temperature regime and naturally-declining photoperiods.

Lifting Date/Cold Storage Treatments

The final phase of the nursery experiment studied the influence of lifting date and cold storage duration on seedling development. The objective was to create a range of physiological seedling qualities within each stock type by altering the lifting date and duration of cold storage. Seedlings were extracted from the styroblocks in mid-November 1986, mid-January and mid-March, 1987 and placed in 1°C rooms for 4, 2 and 0 months cold storage, respectively.

Nursery Experimental Design

A split-plot design was used in the layout of the experiment. Daylength was randomized between halves of the greenhouse and moisture regime between quarters within each half. Each quarter of the greenhouse was divided into eight blocks. Within each of the eight blocks, a group of styroblocks representing each container cavity size (S3 and S4) were randomly assigned to one of the three lifting dates. Analysis of variance of the morphological data were used to test for treatment effects and their interactions (Steele and Torrie 1980). The analyses are not presented in this paper although they are used in data interpretation. We present data means and their standard errors in the figures.

Measurements of Seedling Morphology

Shoot elongation of five seedlings within each of the eight blocks per treatment combination of container size, day length and moisture regime were measured at 1-2 week intervals from June 6 until October 17, 1986 (40 seedlings per treatment combination).

In another subsample, three seedlings from each of the eight blocks per treatment combination were randomly selected and extracted at each of the three lift dates for determination of shoot and root dry weights, and root collar diameter (24 seedlings per treatment combination per lift date = 192 seedlings per lift date).

Measurements of Seedling Physiology

At each lifting date, seedling subsamples were randomly extracted for testing in each of the lift/cold storage treatments (table 1). Root growth capacity (RGC) (Burdett 1979) and dormancy release index (DRI) (Ritchie 1984) were measured on equal numbers of seedlings at each of the three treatment periods A-C. For each test, eight replicates of three seedlings each per treatment combination (container size; photoperiod; moisture regime) were grown in pots containing a 3:1 mixture of peat and vermiculite with 2 $kg \cdot m^{-3}$ dolomite lime added. The pots were placed in a completely random design within growth rooms with day/night temperatures set at 22°/18°C, 55 % relative humidity, and a photoperiod of 16 h provided by mixed fluorescent and incandescent lighting with a photosynthetic photon flux density of 200 $\mu mol \cdot s^{-1} \cdot m^{-2}$. Growth room temperatures for the test were as prescribed by D. Simpson (Kalamalka Research

Table 1.—Summary of test periods for the lift date/cold storage treatment combinations.

Lift Date	Cold Storage Duration (Months)		
	0	2	4
Nov. 15	A	B	C
Jan. 15	B	C	
Mar. 15	C		

Period A: 8 treatments
Period B: 16 treatments
Period C: 24 treatments

Station, B.C. Forest Service, personal communication, Oct. 2, 1985).

Seedlings being tested for RGC were extracted from the pots 1 week later, the soil media carefully removed from around the root plugs and the new white growing tips (> 1 cm in length) scored using Burdett's (1979) semiquantitative scale of 0 to 5.

Seedlings being tested for DRI were placed in the growth rooms under similar conditions to the above. The pots were watered twice a week to maintain soil moisture level at, or near field capacity. Seedlings were assessed daily to determine the number of days to terminal budbreak (DBB); buds were considered to have broken when the bud scales parted and needles extended at least 1 to 2 mm. The dormancy release index values were calculated after the equation [1] given by Ritchie (1984). Fully chilled western hemlock seedlings take 9 days to break bud; hence the numerator = 9. Therefore, at the peak of winter dormancy, as defined by Doorenbos (1953), seedlings have a DRI value near 0; when nearing full release from winter dormancy, the DRI value approaches 1. Data from the RGC and DRI tests were subjected to analysis of variance according to a completely random design.

$$[1]\ DRI = \frac{9}{DBB}$$

RESULTS

Seedling Morphology

Container size had a significant ($P<0.001$) influence on seedling height growth with seedlings in the S3 container being shorter than those in the larger S4 container. As this trend was consistent across all morphological variables measured, only data from the S4 container (PSB 415B) are presented (fig. 1). There were no interactions among the main treatment effects of container size, daylength and moisture regime for seedlings sampled at the end of the growing season.

Seedlings exposed to short days ceased shoot elongation by the end of the dormancy induction treatment period (week 26). Shoots of seedlings under long days continued to extend until mid-October when they formed a terminal bud (week 35) (fig. 1). Moisture stress significantly ($P<0.001$) reduced shoot length but not to the same degree as was achieved with short days. Moisture availability primarily influenced the rate of growth whereas short days affected the phenology of growth.

By mid-January (Lift 2), short days, moisture stress, or both of them produced seedlings with significantly smaller shoot dry weights that those grown under no moisture stress and long days (fig. 2a). In relative terms, moisture stress usually resulted in a greater reduction of shoot dry weight and stem diameter than exposure to short day lengths (fig. 2a and 2c). Exposure to short days did not result in a significant reallocation of dry matter to

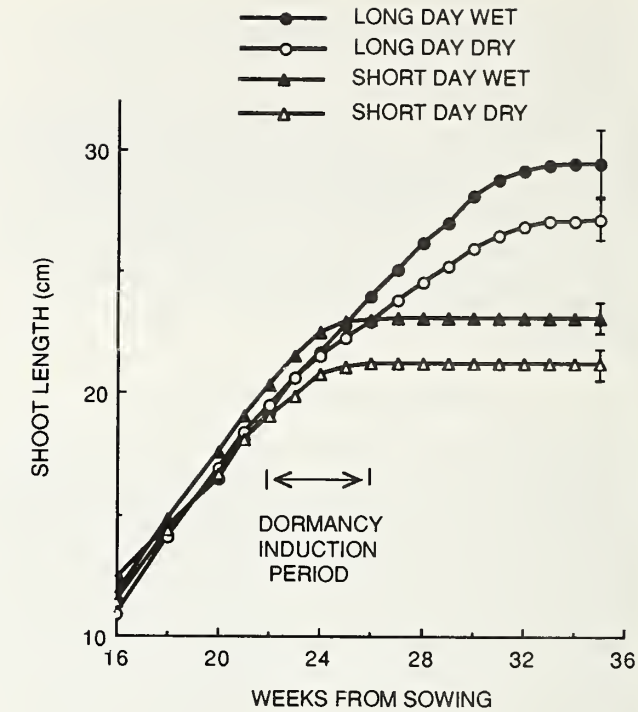

Figure 1.—Shoot length of western hemlock seedlings grown in the larger S4 container (PSB 415B) subjected to dormancy induction treatments, applied for 4 weeks beginning in mid-July (shown by the horizontal arrow). Vertical lines indicate ± 1 SE.

the roots and moisture stress under long or short days simply reduced root dry weight (fig. 2b)

Seedling Physiology

Lifting date and length of cold storage had a highly significant ($P<0.001$) effect on RGC (table 2 and fig. 3). Container size and day length had a small, but significant effect, respectively; the larger S4 container and the short day treatments gave higher RGC (2.6 each) than the smaller cavity size and the longer days (RGC 2.4 each). For seedlings that were not cold-stored, RGC values increased significantly ($P<0.01$) between mid-November and mid-March. Seedling RGC values also significantly ($P<0.01$) increased with time in cold storage with the exception of the November-lifted stock that was stored for two months.

Later lifting dates and longer lengths of cold storage both significantly ($P<0.001$) increased DRI (fig.4). Some seedlings lifted in November (Lift 1) took more than 65 days to break bud resulting in a very low mean DRI value of 0.30. Those lifted in January (Lift 2) had lost a considerable amount of dormancy with a mean DRI value of 0.56 while those lifted in March (Lift 3) were fully released from dormancy with a DRI value of 1.00. While there were several significant treatment interactions

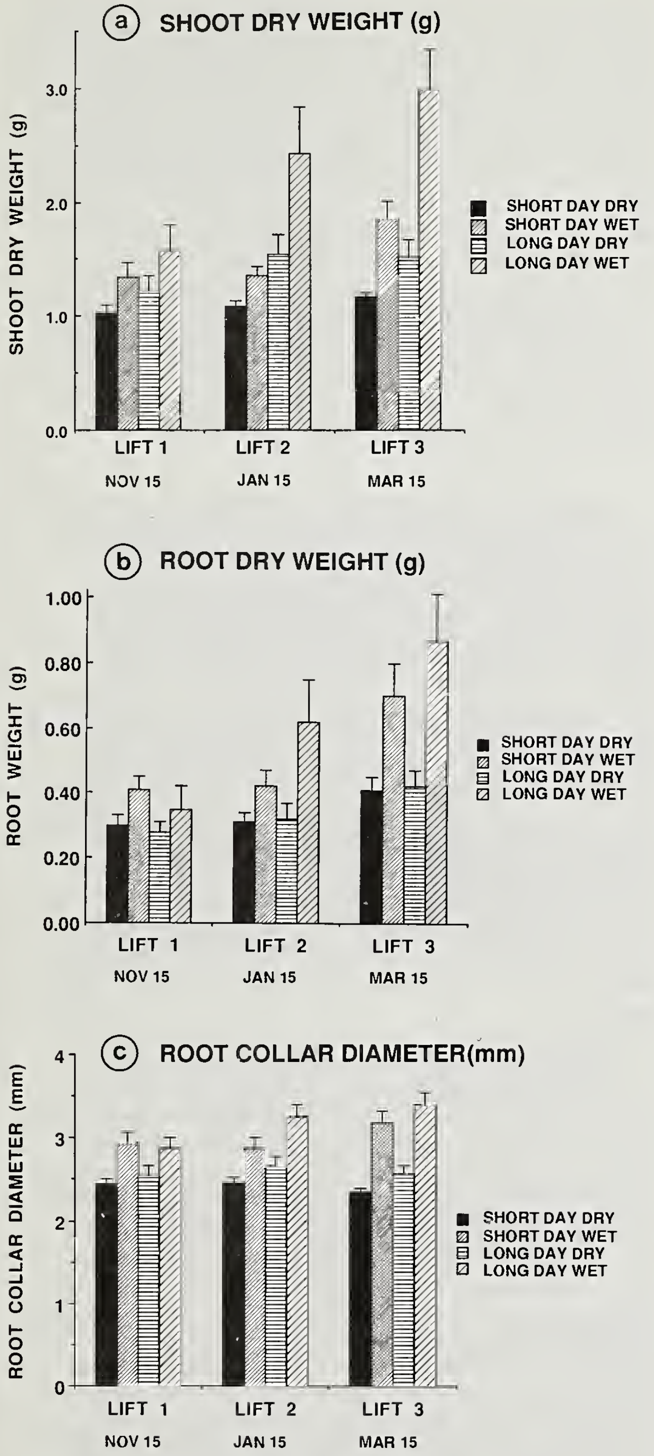

Figure 2.—Shoot dry weight (a), root dry weight (b) and root collar diameter (c) of western hemlock seedlings grown in the S4 container (PSB 415B) that had been subjected to four dormancy induction treatments (short day dry, short day wet, long day dry and long day wet) applied for 4 weeks beginning in mid-July, and three lifting dates (Nov. 15, Jan. 15, Mar. 15). Vertical lines indicate 1 SE within lifting dates.

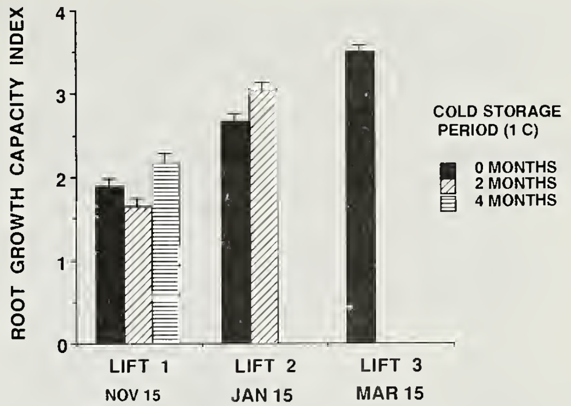

Figure 3.—Root growth capacity index of western hemlock seedlings for all treatment combinations lifted at three dates and cold stored for various lengths of time. Vertical lines represent 1 SE.

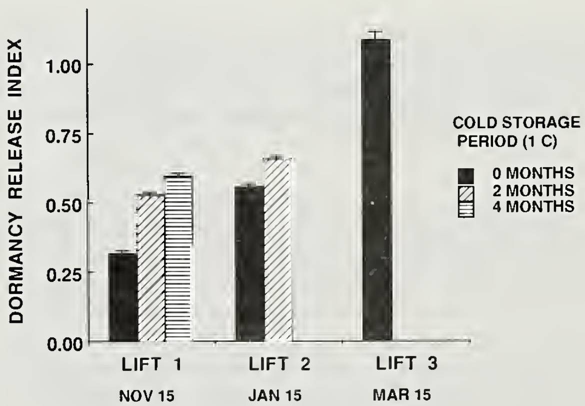

Figure 4. —Dormancy release index of western hemlock seedlings for all treatment combinations lifted at three dates and cold stored for various lengths of time. Vertical lines represent 1 SE.

(table 2) seedlings in the S3 containers had generally higher DRI values than those in the larger S4 containers and those seedlings subjected to short days had higher DRI values than those in the long day treatments. Moisture stress effects were also significant ($P<0.05$), an average of one day more being needed to break bud than in plants grown without moisture stress.

DISCUSSION

All treatment combinations in the nursery - container size, day length and degree of moisture stress - had a significant effect on seedling morphology. The larger container provided the seedlings with 80 % greater rooting volume and growing space. As a result, seedlings grown in the S4 container were taller (26 vs 24 cm), had greater

Table 2.—Anaylsis of variance summary of treatment effects on root growth capacity (RGC) and dormancy release index (DRI).

Treatment		RGC	DRI
Lift/Storage	(L)	***[1]	***
Container size	(S)	**	***
Daylength	(D)	*	***
Moisture	(M)	NS	*
C x L		NS	**
D x L		***	***
M x L		NS	NS
C x D		NS	NS
C x M		NS	NS
D x M		NS	***
C x D x M x L		NS	NS

[1]P<0.001 (***); <0.01 (**); <0.05 (*)

shoot dry weight (1.3 vs 0.8 g at Lift 1) and a larger root collar diameter (2.7 vs 2.2 mm at Lift 1) than those seedlings grown in the S3 container. As the effect of container size was so consistent throughout the study, it will not be discussed further .

Short days, applied in mid-July, rapidly arrested shoot elongation in western hemlock seedlings but moisture stress did not and, when used in combination with short days significantly reduced the number of needle primordia formed in the bud (O'Reilly et al. 1989a). Moisture stress also reduced shoot dry weight and stem diameter, most likely the result of reduced rates of photosynthesis caused by stomatal closure (Osonubi and Davies 1980). Moisture stress has been shown to produce terminal buds (Cheung 1973) and significantly reduce shoot growth of western hemlock seedlings (Cheung 1973; Nelson and Lavender 1976); unfortunately, the degree of moisture stress was not documented in these studies. In the present study, moisture stress (predawn average of -1.0 MPa) did not trigger bud development. In previous studies of other conifers (Lavender et al. 1968; Macey and Arnott 1986; Young and Hannover 1978), more severe stress levels have caused the formation of a terminal bud and arrested shoot elongation. Bud induction may require higher levels of moisture stress than those used in our study; however, this could result in mortality of western hemlock seedlings as they are sensitive to water stress. Some seedlings in our experiment died when predawn shoot water potentials decreased to -1.5 MPa.

Short days arrested shoot growth but did not result in a significant reallocation of dry matter to the roots as observed in pine seedlings (Ledig et al. 1970). Results similar to ours with western hemlock have been reported by Burdett and Yamamoto (1986) for Pinus contorta Dougl. and by Heide (1974) for Picea abies (L.) Karst.

Seedling quality assessment should be based on measurement of several physiological parameters (Ritchie 1984). In our experiment, we used RGC (Burdett 1979) and DRI (Ritchie 1984) to measure the impact of lifting date and cold storage duration on the seedling quality of western hemlock. The intensity of seedling dormancy weakened over the winter with DRI values rising consistently from mid-November (DRI= 0.3) to mid-March (DRI= 1.0). Western hemlock seedlings were released from dormancy at a slower rate in cold storage than those that were held in the nursery throughout the winter. Similer results were found for Douglas-fir and Ritchie et al. (1985) speculated that this was because (a) the temperature in cold storage (1°C) is below the optimum for dormancy release (4°C), (b) intermittent warm periods during the winter accelerates dormancy release and (c) absence of daily photoperiod may retard dormancy release in storage.

Subjecting seedlings to short day lengths in July to arrest height growth in the nursery will tend to result in an earlier release from dormancy in the next growing season; short day seedlings lifted in March flushed 2-3 days sooner than those grown under long days. This effect was enhanced by duration of cold storage. November-lifted seedlings under short day treatments flushed from 10 to 15 days sooner than those grown under long days. Using moisture stress as a means of controlling shoot growth in the nursery had a weakly significant (P<0.05) effect on the number of days it took the seedlings to break bud. Trees lifted in March that that been subjected to moisture stress flushed on average one day sooner than those grown under no moisture stress but considering the risk of mortality in western hemlock, the treatment is not recommended. In addition, seedlings planted in the spring that are predisposed to flush sooner stand a greater chance of being damaged by late-spring frosts.

RGC values were low for seedlings lifted in mid-November and gradually increased throughout the winter with later lifting dates. Similar observations have been made by D. Simpson (personal communication) for Picea glauca (Moench) Voss and by Mattson (1986) for Pinus silvestris L. In general, RGC values also rose while in cold storage, something also noted by Burdett and Simpson (1984) for Pinus contorta L. Therefore, a positive relationship exists between dormancy intensity and RGC in western hemlock seedlings. This is supported by the observation of consistently lower RGC and DRI values for seedlings that were cold stored versus those that remained in the greenhouse and were not stored. It is possible that the mechanisms controlling a seedling's RGC, DRI and chilling requirement are linked as suggested by Ritchie et al. (1985). Moisture stress during the growing season, had no significant effect on seedling RGC; short days resulted in a small, but significant increase.

CONCLUSION

The results of this study indicate that short days are the most effective method of controlling shoot growth of western hemlock seedlings in the nursery. Moisture

stress did not do this effectively and significantly reduced the final values for all morphological variables measured. In terms of seedling physiological quality as indicated by RGC and DRI values, the results indicate a preference for spring lifting of this species either immediately before planting in March or after two months of cold storage from a mid-January lifting date.

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245 # Height Control of Interior Spruce by Means of Photoperiodic Induction[1]

C.D.B. Hawkins and D.A. Draper[2]

Abstract.--Four blackout periods were each applied for 3 durations to control height in interior spruce species at Red Rock Research Station (RRRS). In all six seedlots tested, height control could be achieved without significantly impacting end of season root collar diameter (caliper) or root mass. This finding is contrary to current nursery dogma. Evidence of physiological changes within treatment will be the basis for further studies at RRRS.

INTRODUCTION

In northern latitude nurseries the need to induce apical budset to limit height growth of spruce to desired standards is a recognized cultural challenge (Van Eerden, pers. comm. IX/87[3]). Often drought or nutrient stressing techniques (D'Aoust and Cameron 1981; Matthews 1981; Johnson 1985) are used, with the former the most common. However, drought stressing can have negative biological implications (Johnson 1985; MacDonald and Owens 1988), and height control through nutrient stress is not well understood in conifer crops.

An alternative to drought stressing may lie in blackout (photoperiodic induction of budset: Arnott and Mitchell 1981; Arnott 1982). In blackout treatments, the natural day length is artificially shortened prior to normal budset, thus simulating a later time in the growing season. This can result in cessation of height growth, apical budset and the initiation of frost hardiness/dormancy induction processes (Colombo et al. 1981).

The conventional photoperiod treatment in southern B.C. nurseries is to place seedlings in constant 8 h day 16 h night regimes on about 01 July for 4 weeks (Matthews 1983; MacDonald and Owens 1988). This results in budset but at the loss of potential photosynthate, especially at more northern latitudes. Another consequence of this treatment regime is the substantial difference betweeen treatment and ambient day length experienced by the plant upon removal from blackout. There can be as much as an 8 h increase to ambient day length

An alternative approach to constant night length for a given period of time is to develop photoperiod (PP) treatments which parallel the natural ephemeris at a particular nursery latitude. Thus while photoperiod is offset in terms of actual night hours, the treatment ratio of day to night length would parallel over time that of the ambient ephemeris (Figure 1). At RRRS, with treatment begining on 06 July (114 days after sowing), this results in dynamically increasing night lengths, rather than conventional static night length over the blackout treatment periods. The experimental advantages to this dynamic treatment approach are; constant difference between a given blackout treatment and ambient day length at the conclusion of all treatment durations, increased use of northern latitude long days, and inclusion of ambient ephemeris conditions as a formal 'control' level in treatment comparisons.

This study reports on the use of dynamic blackout regimes for height control of interior spruce.

METHODS

Six spruce seedlots (Table 1) were sown on 14 March 1988 into BCFS/CFS 313[B] polystyro blocks (764 cavities m^{-2}) containing a 2 parts peat, 1

[1] Poster presented at Combined, Western Forest Nursery Council, Forest Nursery Association of B.C. and International Forest Nursery Association Meeting; Vernon, B.C., August 8-11, 1988.

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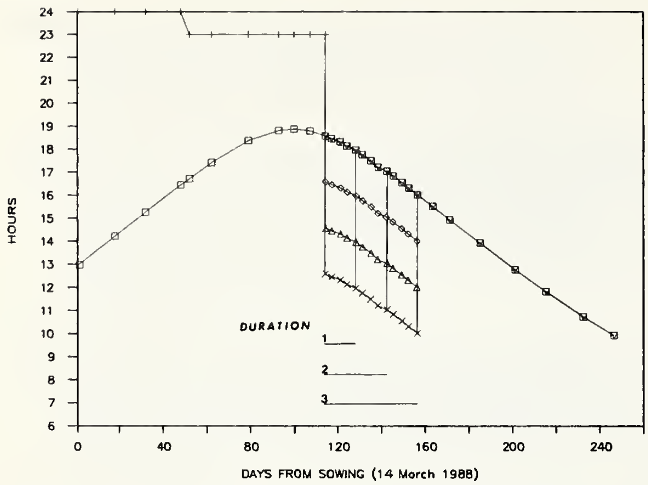

Figure 1.--The ephemeris (natural day length + civil twilight) at RRRS (latitude 53°45' N, longitude 122°41' W), ☒, showing the blackout treatment regimes tested. Photoperiod applied to crop prior to blackout treatment, (+); 17 h (◇), 15 h (△), and 13 h (X) photoperiods during 2, 4 or 6 weeks of blackout D1, D2 or D3, respectively; and ambient photoperiod during and after blackout application (☒).

part vermiculite growing media. Gypsum and 12 mesh lime were added to the media at rates of 1.0 and 0.9 kg m^{-3}, respectively. Germination was carried out in Harnois[4] greenhouses as described by Hawkins and Draper (1988) equiped with a reflective outer cloth (Enershade[5] LS11, 95% blockage) and an inner black absorbent cloth (Enershade[5] 100 S/B, 100% blockage) blackout system[5]. Thermal regimes were 20° C for 5 days and then 20/11° C for 13/11 h, day/night for 4 weeks. Five weeks after sowing a 20-8-20[6] fertilizer regime modified from Draper and Hawkins (1988) was applied to the crop at a rate of 60 ppm N[7]. Heating setpoints[8] were changed to 19/13° C for 16/8 h, day/night at this time. All greenhouse and blackout systems were controlled with an ESC 2000[9] computer system.

All stock was grown under continuous photoperiod until 6 May, then it was growm under a 23 h photoperiod until blackout treatments were initiated on 6 July 1988. Four blackout treatments were chosen (Figure 1), ambient (nominal 19 h) nominal 17 h, 15 h, and 13 h photoperiods. Each was applied for 2, 4 and 6 weeks duration. Times of blackout were changed daily and curtains were closed at the desired evening time, opened after civil sunset, closed again prior to civil sunrise, and opened at the desired time in the morning. The extra opening was to facilitate humidity regulation. At the end of each blackout treatment, stock was returned to ambient photoperiod and grown under it until lifing and storage in early November.

Analyses that have been or will be carried out on these treatments[10] include seasonal serial height determinations; seedling morphology (height, caliper, root and shoot masses) over the season; timing of frost hardiness and dormancy induction processes; developmental anatomy of buds for all treatments in one seedlot; post-cold storage phenology including LT_{50}[11] assessments; mitotic indices; farm-field outplantings; and planting of all seedlots back in location of origin.

RESULTS

Due to the complexity of this trial (72 treatments) and because similar treatment

Table 1.--Seedlot (SL), species (SPP), and approximate elevation (ELEV), latitude (LAT) and longitude (LONG) of origin of the stock.

SL[1]	SPP[2]	ELEV m	LAT °N	LONG °W
5261	Se	1650	49°20	119°30'
4311	Se	1435	50°50	120°30'
8482	Se	1140	52°15	120°30'
5993	Sw	760	54°20	125°30'
8779	Sw	1067	55°45'	122°30'
3958	Sxs	400	55°00'	128°45'

[1] British Columbia Forest Service (BCFS) registered seedlot number.
[2] Species abbreviations: Se, _Picea engelmannii_ Parry; Sw, _P. glauca_ (Moench) Voss; Sxs, _P. glauca_ and its naturally occurring hybrid with _P. sitchensis_ (Bong.) Carr.
[3] Courtesy of G. Kiss of the BCFS interior spruce tree improvement programme.

[4] R: mention of a trademark name, proprietary product or firm does not imply recommendation by the B.C. Forest Service to the exclusion of others in the market place.
[5] Supplied by Van Rijn Enterprises Ltd., Stoney Creek, ON, L8E 4C3 Canada
[6] 20-8-20 "Forest Seedling Special" supplemented with "Plant-Prod" Chelated Trace Element Mix (both from Plant Products Fertilizer Ltd., Bramalea, Ont., L6T 1G6), solubor and $CuSo_4$ at rates of 40.0, 1.2, 0.08 and 0.02 g l^{-1} of stock solution, respectively.
[7] N application increased to 90 ppm in early July and gradually reduced to 30 ppm by early October.
[8] This setpoint maintained until 20 July when setpoints were gradually lowered, to assist in frost hardiness / dormancy induction processes, reaching 9/1° C for 11/13 h day/night on 26 Oct.
[9] Energrated System Consultants Ltd., Surrey, BC V3W 8V3 Canada.
[10] 4 photoperiods X 3 durations X 6 seedlots = 72 treatments.
[11] Temperature required to damage 50% of the seedlings in a given phenological class.

responses were observed for all seedlots, results (one month prior to lifting) are presented for one seedlot (3958).

Serial height increments are presented for all photoperiods (PP) at 2, 4 and 6 weeks duration (Figure 2). Only the 13 h PP was effective for height control after 2 weeks of application (Figure 2a), whereas both 13 and 15 h treatments were effective after 4 and 6 weeks application.

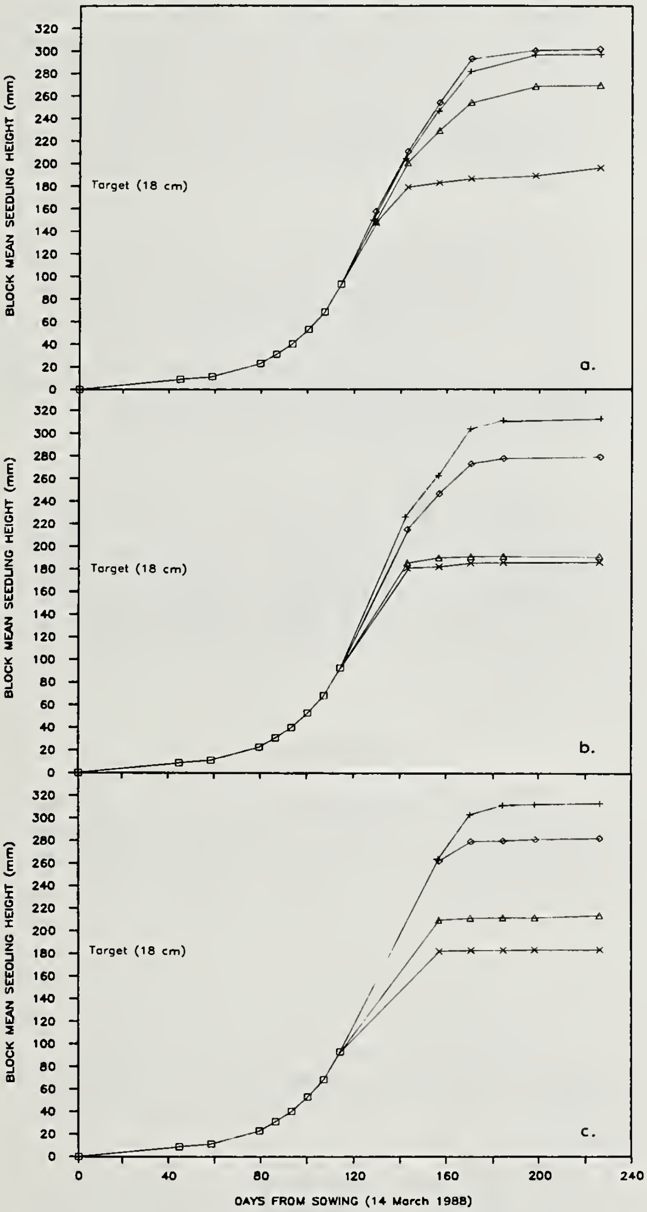

Figure 2.--Cummulative mean seedling block height (based on a serial sample of 10 seedlings from each of six blocks) for seedlot 3958.
a) all PP applied for 2 weeks (D1);
b) all PP applied for 4 weeks (D2); and
c) all PP applied for 6 weeks (D3).
Pre-blackout ambient (⊠), nominal 19 h (+), 17 h (◇), 15 h (△), and 13 h (X) photoperiod treatments.

Table 2.--Seedlot 3958 (Sxs) treatment (P D) mean[1] and standard error (SE) of caliper (root collar diameter), shoot (SDW) and root (RDW) dry weights, and shoot to root ratio (S:R) six weeks after removal of the longest durations from blackout.

P[2]	D weeks		Caliper mm	SDW mg	RDW mg	S:R
13	2		3.52	1593	572	2.78
		SE	0.115	126.4	28.6	nc[3]
13	4		3.33	1450	620	2.34
		SE	0.156	139.7	91.8	nc
13	6		2.56	1270	560	2.27
		SE	0.115	93.3	76.3	nc
15	2		3.29	1989	445	4.47
		SE	0.212	261.4	79.3	nc
15	4		2.95	1361	485	2.81
		SE	0.222	129.4	26.8	nc
15	6		3.01	1528	567	2.69
		SE	0.173	110.4	64.0	nc
17	2		3.33	2236	492	4.54
		SE	0.112	187.0	59.4	nc
17	4		3.04	1681	366	4.59
		SE	0.198	118.8	44.4	nc
17	6		3.38	2080	503	4.14
		SE	0.146	167.7	39.0	nc
19	2		3.31	2084	503	4.14
		SE	0.179	172.0	63.5	nc
19	4		3.28	2023	385	5.25
		SE	0.154	187.5	40.3	nc
19	6		3.15	1918	392	4.89
		SE	0.107	142.3	55.8	nc

[1] Each mean is from a random sample of 18 seedlings.

[2] Photoperiods (P): nominal 13 h, P1; nominal 15 h, P2; nominal 17 h, P3; and nominal 19 h (ambient), P4. Durations (D): 2 weeks, D1; 4 weeks, D2; and 6 weeks, D3. All blackout periods were followed by a common ambient light regime.

[3] nc, not calculated.

Seedling caliper was reduced by 13 h PP applied for 6 weeks (Table 2). Root dry weight was similar between photoperiod treatments but shoot dry weight was reduced by shorter photoperiods (Table 2). Shoot to root ratios varied but generally were largest in the longer photoperiod treatments (Table 2).

Foliage frost hardiness occurred soonest in the shortest photoperiod applied for the longest duration[12]. Seedlot was also important in

[12] Assessed using the $-18°$ C test. Stock is held at $+3°$ C for 1 h, cooled to $-18°$ C at $6°$ C h^{-1}, held at $-18°$ C for 1 h, ramped to $3°$ C at $6°$ C h^{-1}, held at $3°$ C for 1 h, and then placed in a standard environment (30/25° C, 16/8 h, day/night, RH 75%, and light intensity of 500 µmols) for 1 week and then evaluated.

determining frost tolerance because the more northerly the origin of the seedlot, the sooner it achieved frost hardiness (not presented). The Sxs seedlot was the last to attain foliage frost hardiness.

DISCUSSION

For this vigorous hybrid seedlot, little or no height control was achieved with longer PP treatments, regardless of the duration of their application (Figure 2). However, adequate height control was achieved with minimal impact on the other variables using the shorter, but still relatively long, PP treatments.

Two weeks of nominal 13 h PP treatment resulted in control about target heights, with associated good caliper and plant mass relationships (Figure 2a, Table 2). This treatment however, produced considerable lateral lammas growth in September (not presented) indicating that it is not a suitable treatment at this latitude.

Application of blackout for four weeks at nominal 13 h or 15 h PP resulted in good control of height about desired targets, with acceptable caliper and plant mass relationships (Figure 2b, Table 2). Based on this preliminary data, it appears that four weeks of nominal 13 h PP resulted in better quality nursery stock. There was no lammas growth with either of these treatments. The 13 h PP stock also achieved frost hardiness earlier than did the 15 h PP stock. The longest application of blackout for the nominal 13 h or 15 h PP also achieved the desired control of height but caliper was much reduced for stock from the shortest PP treatment (Figure 2c, Table 2). Again, there was no lammas growth.

As blackout installation is expensive, there often is a desire by nurserymen to get more than one crop rotation through a blackout equipped house. Therefore, the shortest duration which achieves the desired nursery results is the most attractive. In this case, it is probably four weeks of 13 h PP.

The greater root masses observed under the longer blackout treatments (Table 2) are a result of a rapid and major shift in carbon allocation to the roots, about two weeks after the onset of blackout (not presented). This presumedly occurs because of the changes in plant growth substance concentrations associated with the induction of terminal budset. There is a slowing in the rate of root mass increase for stock from the shorter PP treatments as frost hardiness increases. This is probably a result of decreased rates of photosynthesis during the period of increasing frost hardiness in spruce (Hawkins et al. pers. comm. III/87[13]). Based on projections at this time, there will be little difference in root mass oetween treatments at the time of lifting and storage, while the large differences in shoot mass will remain.

The blackout treatments which are most appealing in this study are the longest ones. However, these nominal 15 h and 13 h day treatments induce responses that are to be expected from much shorter conventional static 8 h or 10 h days (Hawkins and Hooge[14], table 1). It appears that the dynamic approach used in this study enhanced seedling response to shortened days. Perhaps, seedlings not only respond to the absolute day length but to the rate at which the day length is changing, i.e. the 'dynamic day'.

The best dynamic blackout treatments have resulted in stock which is in balance (shoot:root ratios), has good root mass, has achieved early frost hardiness, and has adequate time for dormancy induction processes. These results run counter to traditional local nursery belief which suggests that blackout treatments result in seedlings with inadequate root mass and insufficient caliper.

Regardless of what the stock looks like at the nursery gate, the potential liabilities presented at these meetings[14,15] of stock grown under blackout must be kept in mind. That is, the accelerated spring flush and the delayed fall budset. Therefore, the nursery treatment cannot be fully evaluated until after early field assessments are in.

ACKNOWLEDGEMENTS

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245

Heating System, Germination Temperature and Post Germination Fertilizer Regime Effects on White Spruce Nursery Growth[1]

C.D.B. Hawkins,[2] D.A. Draper,[2] and R.Y.N. Eng[3]

Abstract.--Morphology of white spruce 1-0 seedlings grown with under-bench heating did not differ from those grown with over-bench heating. No differences were observed between 20/11°C (12/12 h, day/night) germinated seedlings and 20/20°C germinated seedlings, although the heating costs of the latter were almost double. Fertilization with N-P-K 20-8-20 produced shorter seedlings with greater root mass than a 20-20-20 plus 10-52-17 fertilizer regime.

INTRODUCTION

The accelerated rate of backlog reforestation programs in north central British Columbia challenge northern latitude nurseries to develop cultural techniques for the production of cost-effective and high performance seedlings. Research specific to northern latitude container seedling production is relatively scarce. Major concerns of northern growers are heating costs during the March to April germination period, crop height control and achieving adequate root mass at harvest.

This report describes trials carried out at Red Rock Research Station (RRRS), located near Prince George, B.C. (Lat. 53°45'N, Long. 122°41'W), to evaluate the effect of:

1. germination temperature setpoints and greenhouse heating systems on the energy costs and morphological development of white spruce, and

2. the effect of two fertilizer regimes on crop morphological development.

METHODS

A white spruce (<u>Picea glauca</u> (Moench) Voss) 1-0 container crop was sown on March 18, 1987 in BCFS/CFS styroblock 313a in a mixture of 2 peat moss : 1 vermiculite, incorporating Osmocote(R) (18-6-12) and 12 mesh lime at 6.5 and 2.0 kg m^{-3}, respectively. Three treatments, combining air temperature setpoints and greenhouse heating systems, were tested for five weeks beginning on 18 March 1987:

1. 20/20°C[4] with over-bench forced air heating
2. 20/20°C[4] with unskirted under-bench forced air heating
3. 20/11°C[5] with unskirted under-bench forced air heating

Block soil temperature averaged 2° C lower than air temperature setpoints. At the end of the five week germination period, all three temperature regimes were changed to 20/13°C[6], and were gradually lowered over the growing season to harden the plants for harvest on November 2.

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[1]Poster presented at Combined Western Forest Nursery Council, Forest Nursery Association of B.C. and International Forest Nursery Association Meeting; 1988 August 8-11; Vernon, B.C.

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[4]20/20°C = 24 h at 20°C air temperature setpoint

[5]20/11°C = 12 h at 20°C air temperature setpoint from 0800 h to 2000 h (day) and 12 h at 11°C air temperature setpoint from 2000 h to 0800 h (night)

[6]20/13°C = 16 h at 20°C air temperature setpoint from 0600 h to 2200 h (day) and 8 h at 13°C air temperature setpoint from 2200 h to 0600 h (night)

Table 1.--Description of experimental treatments by germination air temperature[1], heating system[2] and fertilizer regime[3]. _A priori_ contrasts are specified within the 5 treatments.

Contrast	df[4]	Treatments 20/20°C under-bench 20-20-20	20/20°C over-bench 20-20-20	20/20°C under-bench 20-8-20	20/20°C over-bench 20-8-20	20/11°C under-bench 20-20-20
Germination Temperature Effect	1	1	0	0	0	-1
Heating System Effect at 20/20°C	1	1	-1	0	0	0
Fertilizer Effect[5]	1	1	1	-1	-1	0
Heating Fertilizer Effect[5]	1	1	-1	1	-1	0
Heating by Fertilizer Interaction[5]	1	1	-1	-1	1	0

[1]Germination air temperature: 20/20°C or 20/11°C
[2]Heating system: under-bench or over-bench
[3]Fertilization regime: 20-20-20 or 20-8-20
[4]Degrees of freedom
[5]Contrasts are orthogonal within themselves

Following the germination period, two fertilizer treatments were applied to the 20/20° C temperature treatment germinants:

1. 20-8-20[7] formulation applied for the remainder of the season
2. 20-20-20[8] formulation applied until July 24, followed by 10-52-17[9] formulation until harvest

Both fertilizer regimes were applied at 120 ppm-N until June 11, at 60 ppm-N June 11-Aug 17, and at 50 ppm-N Aug 17-Nov 2. On August 17, each fertilizer treatment was supplemented with a trace element package[10] at 0.75 g l^{-1} of stock solution until harvest on November 2, at which time the seedlings were freezer stored until April 15 when thawing at 5° C was initiated for spring planting on 19 May.

[7]"Forest Seedling Special", Plant Products Fertilizer Ltd., Bramalea, Ontario Z6T 1G1
[8]"Hi-Sol", Green Valley Fertilizers Ltd., Surrey, B.C. V3W 3A8
[9]"Plant Starter", Green Valley Fertilizers Ltd., Surrey, B.C. V3W 3A8
[10] "Plant-Prod Chelated Trace Element Mix", Plant Products Fertilizer Ltd., Bramalea, Ontario Z6T 1G1

Experimental treatments are listed in table 1 with statistical contrasts of interest specified.

RESULTS

Heater running time during germination and hence direct energy consumption costs, were reduced by almost 50 percent using the 20/11° C germination temperature treatment (Fig. 1).

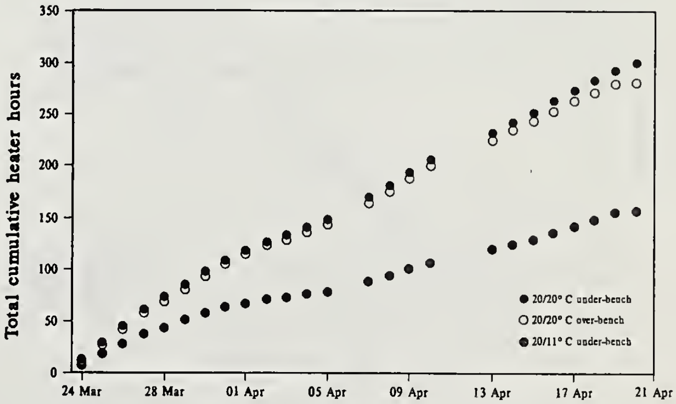

Figure 1.--Greenhouse heater run-time totals during the 1987 germination period.

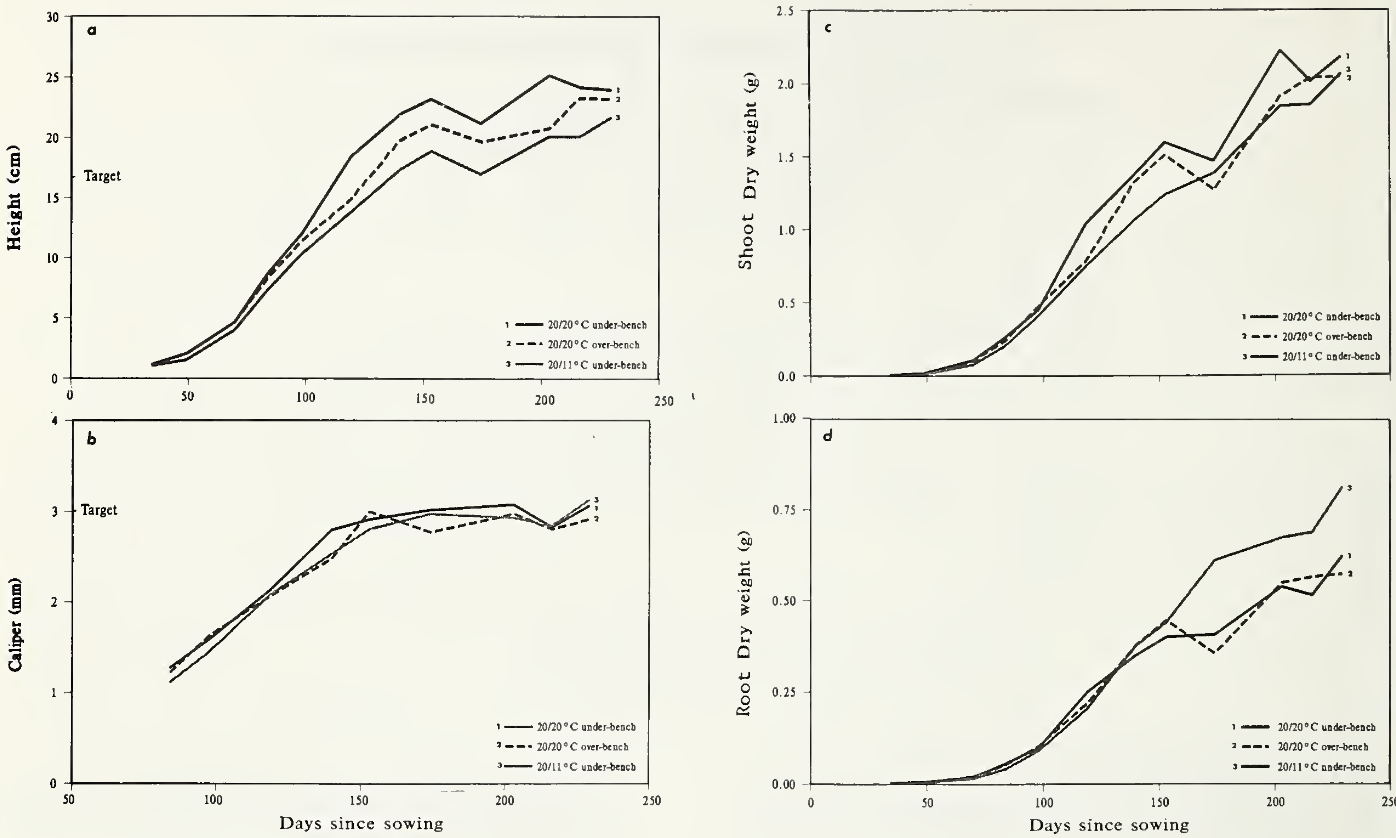

Figure 2.--Cumulative mean height (a), caliper (b), shoot dry weight (c), and root dry weight (d) of white spruce. Values the mean of 20 seedlings.

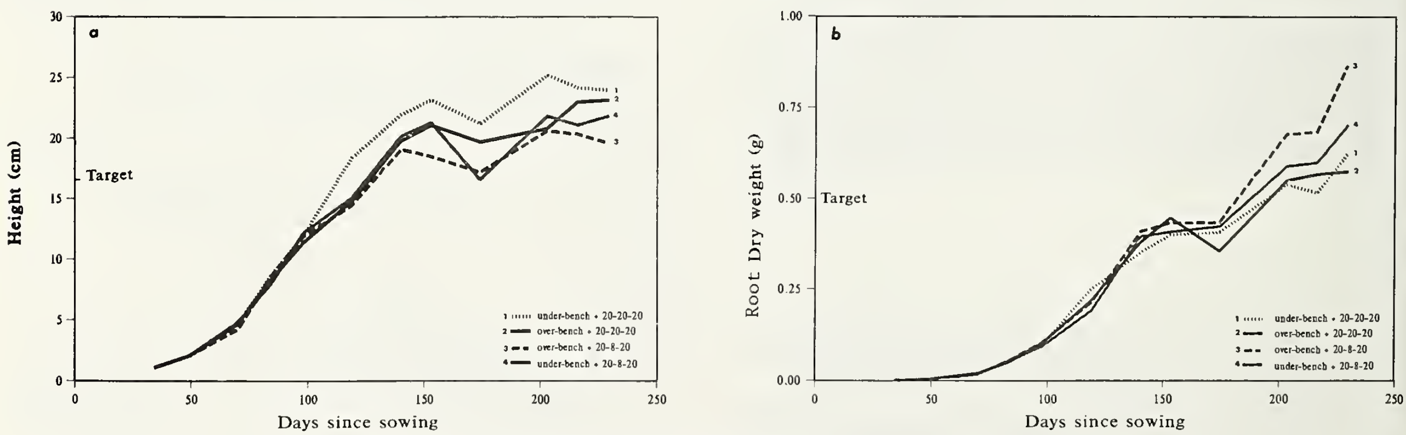

Figure 3.--Cumulative mean height (a), and root dry weight (b) of white spruce. Values the mean of 20 seedlings.

Table 2.--Specified contrast F value and probability of F occurring by chance (bracketed), by morphological variable at end of season.

Contrast	Height (cm)	Caliper (cm)	Shoot Dry Weight (g)	Root Dry Weight (g)
Germination Temperature	1.60 (0.21)	0.24 (0.63)	0.20 (0.65)	2.92 (0.09)
Heating System Effect at 20/20°C	0.20 (0.66)	0.84 (0.36)	0.24 (0.63)	0.20 (0.65)
Fertilizer[1]	5.28 (0.02)	1.86 (0.18)	0.48 (0.49)	5.65 (0.02)
Heating[1] System	1.41 (0.24)	0.27 (0.61)	0.27 (0.61)	0.57 (0.45)
F x HS[2] Interaction[1]	0.29 (0.59)	0.63 (0.43)	0.06 (0.80)	1.85 (0.18)

[1]Signifies contrasts are orthogonal within themselves.
[2]Fertilizer x Heating System

There were no practically significant differences in total heater hours between over- and under-bench heating systems during the germination period (Fig. 1). Expected cost saving with under-bench heating may not have been realized because benches were not skirted.

There were no significant difference in final seedling height, caliper (root collar diameter), root or shoot dry weight at harvest for either germination temperature regime or heating system (Fig. 2 and Table 2). There was no difference in seedling recovery to height and caliper specifications among treatments.

Seedlings in the 20-8-20 fertilizer regime had significantly decreased heights and increased root masses compared to the 20-20-20 regime (Fig. 3 and Table 2). Shoot mass and caliper were not affected by fertilizer treatment (Table 2).

CONCLUSIONS

Heating costs in this study were reduced with the 20/11°C treatment during the germination period without significantly affecting seedling morphology or seedling numbers recovered to height and caliper specifications at harvest.

Significantly shorter seedlings with larger root masses were produced with the 20-8-20 fertilizer regime. Fertilizer regime differences may have been reduced by nutrient available in the Osmocote supplemented growing media.

Results from seedling assessment after one growing season in a farm field environment indicate no nursery treatment differences in survival and performance.

The results from 1987, an excellent growing year, have not been confirmed operationally over a number of growing seasons. Until stock produced via new cultural regimes is field tested, it has no place in operational practices. The goal of forest regeneration is not to produce stock that "looks good" in the nursery but to produce stock that performs well in the field.

ACKNOWLEDGEMENTS

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Blackout and Post Planting Bud Phenology in SxS Spruce Seedlings[1]

C.D.B. Hawkins[2] and B.D. Hooge[3]

Abstract.--Spruce stock grown under three blackout regimes in 1987 was cold stored over the winter and farm-field planted in May 1988. Blackout treatment did not affect root egress but the longest blackout treatment resulted in earlier spring flush, later fall bud set, and increased the susceptibility of seedlings to freezing temperatures.

INTRODUCTION

Sxs spruce (Picea glauca (Moench) Voss and its naturally occurring hybrid with P. sitchensis (Bong.) Carr.) displays typical hybrid vigor making the control of its height growth in the nursery quite difficult. Usually moderate moisture and/or nutrient stress (Macey and Arnott 1986) is used to control height in this species. However, these techniques can have negative biological side effects (Johnson 1985).

Photoperiodic induction of bud set does result in cessation of height growth in spruce (Colombo et al. 1981) and in Sxs it can be an effective means of height control (Table 1). However, Colombo, Odlum and co-workers[4,5] have observed that buds initiated under shortened photoperiods (PP) resulted in shoots which grew four weeks later into the year than did shoots from buds which had been initiated under ambient PP. Prolonged growth, such as this, has the potential to delay frost hardiness/dormancy induction processes, and with it, increase the probability of early fall and/or winter low temperature damage.

The effect(s) of nursery blackout regimes on the first farm-field season bud phenology of Sxs spruce is described here.

METHODS

Sxs stock was germinated in an under bench heated 20° C greenhouse and was raised using thermal and 20-20-20 fertilizer regimes as described by Hawkins et al[6]. Three levels of blackout (as described in table 1) were applied in growth chambers for five weeks commencing on 15 July 1987. After blackout treatment, stock was grown under ambient photoperiod in a greenhouse until lifting and storage on 02 November 1987. The stock was planted in a farm-field[7] at Red Rock Research Station (lat. 53°45' N; long. 122°41' W) on 19 May 1988.

The total number of new roots produced greater than one cm and the average number of days to flush in a growth chamber were determined. As well, the total number of new roots (≥ 1 cm) produced 26 days after farm-field planting was assessed.

Bud phenology was assessed, using a

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[1] Poster presented at Combined, Western Forest Nursery Council, Forest Nursery Association of B.C. and International Forest Nursery Association Meeting; Vernon, B.C., August 8-11, 1988.

[2] Research Scientist, and

[3] Research Technician. British Columbia Forest Service, Research Branch, Red Rock Research Station, RR#7, RMD 6, Prince George, B.C. V2N-2J5 Canada.

[4] S.J. Colombo, K.D. Odlum and C. Glerum. 1986. Measuring and improving the pysiological quality of planting stock. Stock Production Development Activity Seminar, December 1-4, 1986. Timmins, Ontario.

[5] Odlum, K.D. and S.J. Colombo. 1988. Short day exposure to induce budset prolongs shoot growth in the following year. Paper presented at these meetings.

[6] Hawkins, C.D.B., D.A. Draper and R.Y.N. Eng. 1988. Heating system, germination .... fertilizer effects on white spruce nursery growth. Poster presented at these meetings.

[7] 4 blocks each containing 24 seedlings were planted for each treatment.

subjective scale (see table 2), at weekly intervals for the first six weeks after planting and then at approximate fortnightly periods until early November 1988.

RESULTS AND DISCUSSION

The relationship between treatments for the total number of new roots produced (≥ 1 cm) was not the same for growth chamber and field assessments (table 2). This is probably a response to the different soil temperatures for the two determinations. However, under both conditions, new root production was very good. The lowest IRG (Burdett 1979) was 4 for the ambient stock tested in the growth chamber, and 5 for all other treatments.

The average number of days to flush in the growth chamber was greatest in the ambient treatment and least in the 10 h PP treatment (Table 2). This suggests that not only may seedlings grown under blackout regimes have altered fall phenology as reported by Colombo et al.[4,5], but spring phenology also may be altered. The earlier flushing observed for blackout treated stock could predispose it to damage by late spring frosts.

Twenty-two days after planting, 85% of the 10 h PP seedlings had elongating leaders while only 26% of the ambient PP trees were flushing (table 3). Again, the rate of flush of the blackout treated seedlings could increase the occurrence of spring frost damage. However, one week later, all the stock was flushing (table 3, day 28), indicating that the potential window of enhanced damage for the 10 h and 12 h PP treatment stock was not appreciably longer than for ambient PP seedlings.

Table 1.--End of season (02 November 1987) mean morphological measurements[1] and standard error (SE) for height (Ht), caliper (Cal), root (RDW) and shoot dry weights (SDW) of Sxs grown under blackout[2] for 5 weeks[3] and then returned to ambient photoperiod until lifting and storage.

PP	Ht cm	Cal mm	RDW mg	SDW mg
Ambient	29.8	3.63	600	2378
SE	1.0	0.14	57	151
12 h	24.1	3.20	620	1930
SE	0.8	0.15	70	152
10 h	20.1	2.50	450	1458
SE	0.5	0.10	38	107

[1] B.C. Forest Service stock standards for Sxs are: Ht, min/target/max, 14/18/30 cm; Cal, min/target, 2.2/2.6 mm; and RDW, min/target, 500/700 mg. There are no mass standards for the shoot. Each measurement is the mean of 20 trees.

[2] Three blackout treatments applied on 15 July 1987 were: ambient PP, natural day length decreasing from 18:19 h to 16:01 h over the 5 weeks; 12 h constant and 10 h constant PP both applied for 5 weeks.

[3] All stock exceeded minimum height when blackout was applied.

Table 2.--Mean[1] and standard error (SE) of the total number of roots produced (≥ 1 cm) after one week in the growth chamber[2] (GC), 26 days after field planting (AP), and the mean number of days to flush (TF) in a growth chamber for the three photoperiod treatments[3].

PP	Roots ≥ 1 cm GC	Roots ≥ 1 cm AP	TF days
Ambient	20.1	76.9	16.8
SE	4.2	8.4	1.3
12 h	59.9	60.9	10.9
SE	3.5	12.9	0.6
10 h	32.3	45.7	8.4
SE	4.3	4.3	0.3

[1] Each measurement is the mean of 16 seedlings.

[2] In growth chamber at 30/25° C, 16/8 h, day/night, RH 75%, light intensity 500 µ mols for one week; standard BCFS RGC conditions.

[3] See table 1 for treatment descriptions.

Blackout treated stock flushed sooner and continued leader elongation later into the season (table 3, day 112) than did stock from the ambient treatment. On 17 September (day 121), there was a near record low temperature of -6.9° C. This apparently resulted in considerable mortality of terminal buds in the 10 h PP treatment seedlings (table 3, day 137). The altered and presumedly delayed phenology observed in the 10 h PP treatment resulted in the increased mortality following exposure to fall frosts for this treatment. The response of the 12 h PP stock was intermediate between the other two treatments (table 3). On days 135 and 172 this treatment responded more like the ambient treatment than the 10 h PP treatment stock, whereas, very early in the season it responded more like 10 h PP stock (table 2, TF). This suggests that a reacclimation (towards ambient) is possible.

By the time of the last assessment, more than one-third of the trees in the 10 h PP treatment had dead terminal buds and all seedlings with surviving terminal buds were in bud class 5 (table 3, day 172). In just over one month, bud mortality in the 10 h PP stock increased from 25 to 35 percent, indicating the severity of damage to this treatment. However, seedling survival was 100% for all treatments at this time.

The time available for frost hardiness and dormancy induction processes was likely much less in the blackout treated seedlings because of their growing later into the season, and their delay in initiating terminal buds as indicated by

Table 3.--The total number of seedlings, as a percentage, in a given subjective bud class[1] on each sample day in the 1988 farm-field outplanting at RRRS for Sxs spruce subjected to ambient (A), 12 h (12), or 10 h (10) photoperiod treatments (PPT) for five weeks in the nursery during 1987.

Day[2]	Percentage of trees in each bud class																				
	0			1			2			3			4			5			D		
	PPT			PPT			PPT			PPT			PPT			PPT			PPT		
	A	12	10	A	12	10	A	12	10	A	12	10	A	12	10	A	12	10	A	12	10
0	100	100	100[3]																		
11	69	52	16	31	48	84															
22	1	0	1	63	30	14	36	70	85												
28				3	0	0	97	100	100												
54							7	1	0	93	99	100									
96							1	0	1	99	100	99									
112										39	61	79	61	39	21						
137													80	77	70	14	13	5	6	10	25
172																92	86	65	8	14	35

[1] The subjective bud classes are:
Class 0, resting spring terminal bud;
Class 1, swelling terminal bud;
Class 2, flushing (elongating) leader;
Class 3, lateral buds visible on leader;
Class 4, terminal bud scales, bud filling;
Class 5, resting fall terminal bud; and
Class D, dead terminal bud, frost killed.

[2] Days since planting on 19 May 1988, for brevity and clarity, not all sample days are shown.

[3] 84 seedlings were sampled for each treatment

increased bud mortaility. There is a distinct possibility that the 10 h PP seedlings will also undergo considerable winter damage when compared to the other treatments because of the shorter time available for completion of their frost hardiness and dormancy induction processes prior to winter. However, this will not be known until spring 1989 assessments.

CONCLUSIONS

Blackout of Sxs does alter seasonal bud phenology both in the spring and the fall of the following growing season. Stock from shorter day length treatments is placed at greater risk to frost injury in the fall because of the longer fall damage window duration. The duration of altered phenology induced by the blackout treatments is yet to be determined. It appears that stock from the intermediate treatment can reacclimate towards responses more typical of control stock, while stock from the longest PP treatment changes little. If the effect lasts into the second field season it could have a significant impact on seedling form and growth and plantation form and survival.

The present data set does not preclude the use of blackout for height control. A morphologically acceptable seedling was produced from an intermediate blackout treatment which, while altering seedling phenology, did not result in bud damage significantly different from control stock. Therefore, it is reasonable to assume that a compromise can be achieved between blackout period and duration, nursery stock standards, and early field phenological response.

Acknowledgements

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245

Short Day Exposure to Induce Budset Prolongs Shoot Growth in the Following Year[1]

Kerry D. Odlum and Stephen J. Colombo[2]

Abstract.--Short day exposure applied in the greenhouse prior to overwintering container black spruce (Picea mariana [Mill.] B.S.P.) seedlings dramatically influenced the timing and duration of shoot growth in the first year after outplanting. When compared with seedlings grown under natural daylength bud initiation regimes in the year prior to planting, short daylength seedlings flushed sooner in the spring and set bud later at the end of the growing season, resulting in greater shoot growth. The extended duration of shoot growth in SD seedlings is expected to place them at greater risk of damage from both late spring and early fall frosts.

INTRODUCTION

Conifer seedling response to photoperiod has been studied a great deal since early work by Kramer (1936) and is well reviewed by Arnott and Mitchell (1982) and Lavender (1980). In spruce, terminal buds are induced under short daylengths while vegetative shoot growth continues under long days (Dormling et al. 1968). This knowledge is necessary for nurserymen to successfully grow spruce seedlings in a greenhouse. When height growth is needed in a crop, it can be ensured, regardless of the natural daylength, by artificially extending the daylength within the greenhouse or by interrupting the dark period during the night (Arnott 1974). Similarly, by shortening the daylength within the greenhouse a nursery manager can rapidly and uniformly terminate shoot growth and induce budset in his crop at any time of year.

Because of the greater control in production schedules afforded by the use of short daylength exposure, the procedure is now routinely applied in black spruce (Picea mariana [Mill.] B.S.P.) production at approximately 30% of all container seedling nurseries in Ontario.

Daylength treatments applied in the greenhouse are known to influence the timing and/or growth of seedlings the year following treatment, depending upon species (Arnott and Macey 1985, Heide 1974). The objective of this study was to determine whether similar after-effects occur with black spruce seedlings that have set bud under short daylengths in operational greenhouse production.

MATERIALS AND METHODS

Seedlings used in this study were grown operationally in 1986 at a greenhouse nursery near Englehart, Ontario (47°49'N, 94°55'W) where both natural daylength (ND) and short daylength (SD) bud initiation regimes were applied. Seedlings of a site region 3E (Hills 1960) seed source were grown using a schedule similar to that of Carlson (1983) with the exception of bud initiation regimes which are summarized in table 1. The three SD treatments (S1, S2 and S4) varied by time of application while the natural daylength

Table 1.--Greenhouse daylength regimes for bud initiation.

Treatment	Seeding date (1986)	Short day applied (1986)
S1	April 9	July 2
S2	April 9	July 17
S4	April 10	July 29
EG	April 29	n/a
ER	April 9	n/a

[1]Paper presented at the combined meeting of the Western Forest Nursery Council and Forest Nursery Association of B.C., Vernon, B.C., August 8-11, 1988.

[2]Kerry D. Odlum and Stephen J. Colombo are Research Scientists, Ontario Tree Improvement and Forest Biomass Institute, Ontario Ministry of Natural Resources, Maple, Ont.

treatments permitted bud initiation to occur either in the greenhouse (EG) or outside (ER). All seedlings were overwintered outside. On April 30, 1987, seedlings from two FH408 Japanese paperpot® trays were randomly sampled from each of the five treatments and were planted in a randomized block design in a cultivated field at the Midhurst Research Station of the Ontario Tree Improvement and Forest Biomass Institute (44°27'N, 79°44'W). A total of 150 seedlings per treatment were assessed weekly for bud break and shoot elongation. Beginning 39 days after planting and at weekly or biweekly intervals thereafter, a sample of 20 seedlings per treatment was removed randomly from the plantation and shoot tips were examined under a dissecting microscope for signs of bud initiation, evident as newly differentiated budscales at the base of the vegetative apex. Seedling height at planting and new shoot length were measured in the fall, after shoot growth had ceased.

RESULTS AND DISCUSSION

Seedlings that received SD bud initiation regimes in 1986 (treatments S1, S2, S4) began to break bud sooner than did seedlings from ND bud initiation regimes (fig. 1). In general, seedlings from the SD regimes attained maximum percentage bud break 14 days after planting while the seedlings from the ND regimes did not reach that point until 21 days after planting. Heide (1974) found a similar relationship between SD bud initiation regimes and the timing of bud break in Norway spruce (Picea abies [L.] Karst.). It is likely that the earlier flushing SD seedlings in this experiment were at greater risk of being damaged by late spring frosts. Although such frost damage was not observed in this 1987 experiment, it has occurred in a similar trial in 1988 where approximately 41% of the terminal shoots in SD seedlings were killed by late spring frosts as compared with 3% mortality in the shoots from ND bud initiation regimes. The extent of damage to SD seedlings could be expected to vary with timing and severity of frost exposure.

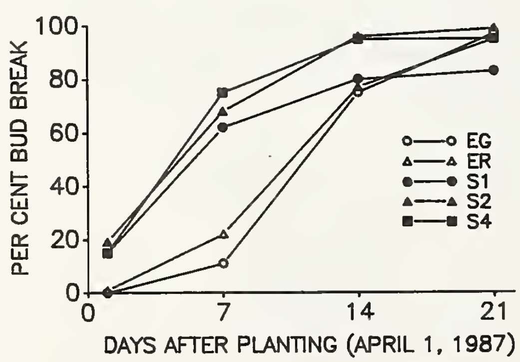

Figure 1.--Bud break in seedlings grown under natural daylength (EG, ER) and short daylength (S1, S2, S4) bud initiation regimes in the previous season.

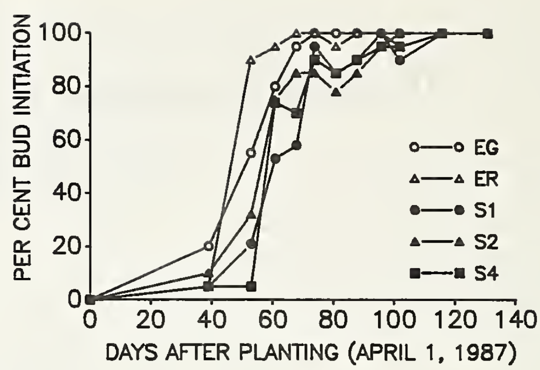

Figure 2.--Bud initiation after planting in seedlings grown under natural daylength (EG, ER) and short daylength (S1, S2, S4) bud initiation regimes in the previous season.

First signs of bud initiation were detected in all treatments 39 days after planting (fig. 2) but 100% bud initiation was not reached in each of the SD treatments until 3 to 6 weeks later than in the ND treatments (fig. 3). The effect of later bud initiation is apparent in the relative proportion of seedlings still exhibiting active growth throughout the late summer (fig. 4). Active seedlings were those in which weekly terminal shoot elongation exceeded 5 mm. After June 3, there were always more SD seedlings active in the plantation than there were ND seedlings. By August 12, 8% of the SD seedlings were still elongating while less than 1% of the ND seedlings were. Because of the greater proportion of SD seedlings continuing growth, a larger number of SD seedlings would be at risk of being damaged by late summer frosts.

Although seedlings from the SD regimes were shorter when planted, their growth after outplanting at the end of the first growing season was greater than seedlings from the ND regimes

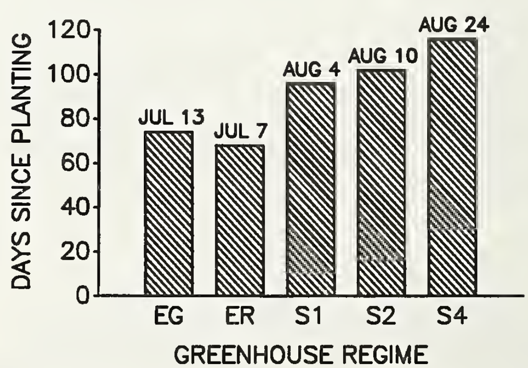

Figure 3.--Date and number of days after planting when 100% bud initiation was attained in seedlings grown under natural daylength (EG, ER) and short daylength (S1, S2, S4) bud initiation regimes in the previous season.

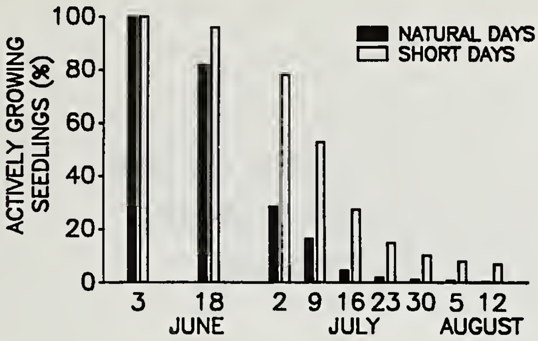

Figure 4.--Percentage of seedlings exhibiting active shoot growth in first season after planting. Natural day values are grand means from EG and ER treatments and short day values are grand means from S1, S2 and S4 treatments.

(fig. 5), primarily as a result of earlier bud break and later bud initiation. Similarly, Heide (1974) found greater growth in Norway spruce seedlings exposed to SD in the previous year for up to 3 years after planting, but did not attempt to correlate this with the timing and duration of shoot growth. In contrast, our results from a plantation estabished in 1986, indicate that after-effects did not persist past the first season in the field.

The mechanism by which a two week short daylength treatment can have such a dramatic effect on the timing and duration of shoot growth in the field more than one year after exposure is still unknown. At the Ontario Tree Improvement and Forest Biomass Institute, studies are

Figure 5.--Shoot measurements for seedlings grown with natural daylength (EG, ER) and short daylength (S1, S2, S4) bud initiation regimes in the previous year. Different letters indicate significant differences ($p<0.05$) between treatment means for seedling heights at planting (lower bars), shoot elongation after planting (upper bars) or total seedling heights (combined bars).

currently in progress to determine some of the consequences of this growth phenomenon. For example, frost hardiness testing in the late summer and autumn is being carried out on outplanted black spruce seedlings from SD and ND regimes to determine whether differences in the timing of frost hardening occur. Intensive monitoring of operationally planted seedlings is underway to assess the risk of damage from frost associated with planting seedlings that flush sooner and set bud later. Needle production in the field is being compared to needle primordia content of the bud prior to planting to determine if free growth accounts for the greater growth found in the SD seedlings. It is yet to be determined whether the nursery production benefits and greater first-year seedling growth potential derived from SD treatment outweigh the risk of frost damage associated with earlier bud break and later budset in black spruce seedlings.

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Recommendations and Alternative Growing Media for Use in Containerized Nursery Production of Conifers: Some Physical and Chemical Properties of Media and Amendments[1]

R.K. Scagel[2] and G.A. Davis[3]

Abstract.-- Physical and chemical properties of various nursery media were examined at the start of the crop cycle of containerized Englemann spruce. Preliminary results showed physical and chemical properties of the peat and amendments are highly variable. Combined, these ingredients produce variable media. The results highlight the need for monitoring the media physical and chemical properties and altering nursery culture to accommodate media properties.

INTRODUCTION

Nursery media contain solids, water, air, and eventually plant roots. The ideal growth medium for nursery culture should: permit healthy root development; be free of pathogens; offer physical stability; and supply water, nutrients, and air. This ideal medium should retain its properties throughout culture and be consistent from one crop to the next (Bunt 1976).

In the real world, peat-based growth media vary in their physical and chemical properties (Haynes and Goh 1978, Prasad 1979). Media also vary in their rate of decomposition (Langerud and Sandvik 1987). Ideal conditions for crop growth are also ideal for media decomposition. Decomposition reduces the aeration porosity of media. Poor media aeration alters root morphology and physiology (McKevlin et al. 1987) and is responsible for decreased seedling vigor and stature (Hocking 1972). Outplanting performance of seedlings grown in poorly aerated media is suspect (Hellum 1981).

Variable peat quality and failure to recognize this variability in crop management has been implicated in the increasing incidence of root diseases in container-grown conifer seedlings. Perlite, wood waste, and rockwool, have been suggested as alternatives to vermiculite in Cornell Peat-Lite mixes (Boodley and Sheldrake 1967) and may provide a means of altering peat properties. Different amendments appear to yield crops with different morphological attributes and plantation survival and growth (Phipps 1974). Amendments alter the porosity and nutritional regimes of nursery culture and, like peat, are variable. Species may respond deferentially to amendments.

STUDY OBJECTIVES

This study examines the physical and chemical properties of various media and amendments. The results report on the initial properties of a variety of media. Future results will report on the degradation of media and cultural consequences for seedling vigor. The preliminary results are presented to permit growers to make comparisons with their media.

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[1] Poster session presented at the Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association meeting; 1988 August 8-11; Vernon, British Columbia.

[2] Rob Scagel is principal consultant with Pacific Phytometric Consultants, Richmond, B.C.

[3] Gerry Davis is a consultant with Soilcon Laboratories Ltd., Richmond, B.C.

MATERIALS AND METHODS

Nurseries were canvassed to determine the range of operational and experimental media being used. Only Englemann spruce crops grown in PSB 313-sized containers were considered. Thirteen media and their amendments were sampled from both coastal and interior nurseries (Table 1) to include a wide range of nursery cultural conditions. Letters reference the media and numbers reference their amendments. Not all the amendments examined were incorporated into the media sampled.

Various physical and chemical properties were examined. Methods of analyses were selected that were used in forest nurseries or related industries. All analyses were carried out in triplicate.

Chemical properties

pH and electrical conductivity (EC) -- pH and EC were measured using a soil:distilled water solution (Day et al. 1979; McKeague 1981). These and other methods are used in the nursery industry.

Ash -- The ash content was determined using the Loss on Ignition method (McKeague 1981). Ash content is expressed on a % oven dry weight.

Table 1.-- Nursery location, media, and amendments used. Media are identified by letters given parenthetically. Amendments are references by numbers.

Nursery	Location	(#)	Media	Amendments Used
1	Coast	(A)	6P:4V:1V	6, 11, 12
2	Interior	(B)	3P:1V	7, 11
	Interior	(C)	3P:1R-	7, 19
	Interior	(D)	1P:1S	7, 14
3	Coast	(E)	3P:2V	9, 11
	Coast	(F)	3P:1S	9, 15
	Coast	(G)	3P:1R+	9, 21
	Coast	(H)	3P:1R-	9, 17
4	Coast	(I)	3P:1V	8, 11
	Coast	(J)	1P:1S	8, 16
5	Interior	(K)	P	10
	Interior	(L)	3P:1R-	10, 17
	Interior	(M)	9P:1R-	10, 17

Media Symbols: P- Peat (1-10);
V- vermiculite (11); Pe - perlite (12);
S- Douglas-fir sawdust (13-16);
R+ - hydrophobic rockwool (17-19);
R- - hydrophilic rockwool (20,21)

Total carbon, nitrogen, sulphur -- Total carbon (TC) and total sulphur (TS) were determined using the Leco Analyzers (McKeague 1981). Total nitrogen (TN) was determined colorimetrically using the Auto Analyzer (Lavkulich 1981). All values are expressed as a % of oven dry weight.

Physical properties

Particle size -- Two methods were used to determine particle size distribution: dry and wet (rubbed fibre) sieve. The dry-sieve analysis is currently used in the British Columbia forest nursery industry to assess peat quality (Gates, pers. comm). The wet-sieve analysis (Day et al. 1979) is the method most often used in the peat industry (Farnham 1968). In both methods four sieve sizes were used: No. 5 (4mm), No. 10 (2mm), No. 20 (0.85mm), and No. 100 (0.15mm). Dry-sieve analyses are expressed as the percentage of air dry mass. Wet-sieve analysis is expressed as a percent of an oven dry mass. The coarse:fine ratio (C:F) is the ratio of weight of particles greater than 2mm ("coarse") to particles less than 2mm ("fine"; Carlson 1979).

Water retention -- Media water contents of 3cm-high, undisturbed container cells contents, were determined at soil water tensions of 0.03, 0.06, 0.10, and 0.33 bars using a Richardson pressure plate apparatus (McKeague 1981). The media water contents are expressed volumetrically (g H_2O/ cm^3) and gravimetrically (g H_2O/ oven dry weight). Expressing results gravimetrically permits relating nursery gravimetric sampling results to lab results.

Watering regime -- During the early growing season each of the participating nurseries determined the gravimetric water contents of the media just before irrigation and 2 hours after irrigation. This sampling includes the extremes of irrigation. These water contents were then compared to the lab-determined gravimetric water retention curve to provide information on the water tensions experienced by the crop.

PRELIMINARY SURVEY RESULTS AND DISCUSSION

Media will be resampled at the end of the crop cycle to determine the degree of media degradation. Gravimetric sampling in the nurseries will be repeated later in the crop cycle. The effect of these media properties on seedling growth, particularly roots, will also be examined. Recommendations cannot be presented without data on the seedlings.

Peats. -- The unamended peats had variable chemical properties (Table 2), particularly total sulphur. All the peats sampled were within the chemical guidelines set out by Carlson (1979). The combination of chemical attributes varies.

Dry-sieve particle size analysis indicated that several peats had many fines (Table 3) and would be regarded as unacceptable by Carlson's (1979) standards. Wet-sieve analysis dispersed many of the aggregates yielding still lower coarse:fine (C:F) ratios. The ranking of the peats changed depending upon the method of sieving used. The C:F ratios may not be adequate to discriminate among peats - similar C:Fs can have very different particle size distributions within each of the broad size classes.

Table 2. Peat chemical properties. Peats have been arranged in order of decreasing pH. pH and EC from an distilled water solution. EC expressed as mS/cm.

Peat	pH	EC	%ASH	%TC	%TN	%TS	C/N
5	4.70	.39	9.8	47.1	1.43	.50	32.9
1	4.49	.32	6.4	41.5	.84	.68	49.4
9	4.40	.30	8.8	43.7	1.09	.72	40.1
3	4.38	.83	6.7	41.5	.87	.44	47.7
8	4.15	.29	7.3	50.8	1.11	.43	45.8
4	4.14	.31	5.2	44.1	1.05	.25	42.0
7	3.99	.14	4.6	46.1	1.06	.14	43.5
6	3.96	.23	7.4	45.9	.94	.12	48.8
2	3.89	.16	6.4	41.8	.81	.11	51.6
10	3.85	.16	5.9	46.4	.75	.10	61.9

Table 3. Peat particle size analysis. Peats have been arranged in decreasing C:F order.

	Mesh Size (% weight retained on sieve)					
Peat	No.5	No.10	No.20	No.100	No.100+	C:F
Dry-Sieve Analysis						
3	38.5	18.0	21.9	20.1	1.5	1.30
2	29.3	20.6	22.1	24.0	4.0	1.00
6	27.5	17.3	20.7	29.3	5.2	.81
10	19.9	20.1	25.1	34.2	.7	.67
8	18.8	14.1	22.2	36.2	8.7	.49
7	14.4	12.6	21.4	41.5	10.1	.37
1	.0	19.3	23.5	44.8	12.4	.24
9	4.2	10.8	24.3	48.7	12.0	.18
4	2.0	10.2	21.3	47.5	19.0	.14
5	3.0	4.6	16.6	58.8	17.0	.08
Wet-Sieve Analysis						
2	14.2	11.8	19.2	29.5	25.3	.35
4	6.2	10.9	18.2	35.9	28.8	.21
1	5.9	10.6	22.5	35.0	26.0	.20
5	5.4	6.8	18.2	44.1	25.5	.14
3	2.8	8.3	20.5	37.2	31.2	.12

Table 4. Peat water retention analysis. Results expressed on a volumetric basis. Peats arranged in order of decreasing aeration porosity (AIR).

	Water tension (bars)							
Peat	0.00	0.03	0.06	0.10	0.33	AIR	BD	PORE
5	86.1	32.3	27.8	24.4	20.2	53.8	.085	93.9
3	96.5	45.5	41.1	34.2	26.4	51.0	.085	94.1
1	82.6	37.4	30.6	27.0	19.6	45.2	.084	94.1
2	80.4	39.4	33.8	30.3	25.1	41.0	.085	94.0
4	71.7	32.0	27.4	23.6	20.0	39.7	.084	94.0

AIR - aeration porosity (% volume)
BD - bulk density (g/cc)
PORE - effective porosity (% volume)

Table 5. Media amendment chemical properties. Amendments have been arrangde in order of decreasing pH. pH and EC from a distilled water solution. EC expressed as mS/ cm. Note: not all amendments examined were included in the media.

#	pH	EC	%ASH	%TC	%TN	%TS	C/N
Hydrophilic rockwool							
20	8.67	.23	99.1	1.20	.01	.59	120
Perlite							
12	7.61	.17					
Hydrophobic rockwool							
17	7.03	.11	99.2	.60	.004	.22	150
18	6.78	.02	99.7	.90	.02	.18	45
19	5.93	.11	97.9	4.50	.21	.01	21
Vermiculite							
11	6.85	.20					
Sawdust							
13	5.68	.07	.70	46.3	.07	.02	661
14	4.36	.22	.11	47.2	.09	.01	524
15	4.03	.44	.40	48.0	.07	.01	686

Other analyses (Table 4) indicated that the peats were very similar in their bulk densities (0.084 to 0.085 g/cc). Over 94% of the volume of the peats is occupied by air (i.e. 6% are solids). Water available between saturation and 0.33 bars ranged from 47 to 60% of the volume of the peat. The aeration porosity of the media did not relate well to the C:F ratio. The largest drop in water retention occurs between saturation and .03 bars. Peat physical properties appeared less variable than the chemical properties. Many of the physical properties (i.e. C:F ratio, air capacity) were outside the guidelines set out by Carlson (1979).

Amendments -- Like the peats, amendments were highly variable in their chemical properties (Table 5). Some of the rockwools had particularly high pH values and total sulphur. Predictably, the Douglas-fir sawdusts had very high carbon:nitrogen ratios and acid pH.

Particle size analysis of the sawdusts (Table 6) indicated that they could be as variable as the peat. One sawdust had a particularly small coarse:fine ratio.

Table 6. Sawdust particle size analysis. Sawdusts arranged in order of decreasing C:F ratio.

#	No.5	No.10	No.20	No.100	No.100+	C:F
	Mesh Size (% weight retained on sieve)					
13	22.6	39.9	31.1	6.0	.4	1.67
14	14.7	40.5	36.0	8.5	.3	1.23
15	2.9	25.0	43.3	27.7	1.1	.39

Table 7. Media chemical properties. Media have been arranged in order of decreasing pH. pH and EC from a distilled water solution. EC expressed as mS/cm.

#	pH	EC	%ASH	%TC	%TN	%TS	C/N
Hydrophilic rockwool-amended media							
G	5.78	2.41	65.7	16.0	.6	.36	26.7
Hydrophobic rockwool-amended media							
M	5.74	.69	29.4	31.4	.8	.13	39.3
L	5.64	.86	55.3	21.9	.5	.16	43.8
H	5.44	3.40	72.2	13.3	1.0	.40	13.3
C	5.18	1.09	27.7	32.9	1.2	.37	27.4
Vermiculite and perlite-amended media							
A	5.27	1.09	40.0	27.6	.9	.35	30.7
Vermiculite amended-media							
E	5.26	2.69	50.2	21.8	1.9	.55	11.5
B	4.82	1.13	24.4	33.4	1.3	.37	25.7
I	4.04	1.84	30.5	31.9	1.1	.44	29.0
Sawdust amended-media							
D	5.15	1.23	7.4	41.2	1	.24	41.2
F	4.44	2.87	5.5	40.4	1.3	.47	31.1
J	3.95	2.27	4.7	41.9	1.2	.37	34.9
Pure peat media							
K	4.45	.80	9.8	38.6	.8	.13	48.3

Table 8. Media wet sieve particle size analysis. Media have been arranged in decreasing C:F order.

#	No.5	No.10	No.20	No.100	No.100+	C:F
	Mesh Size (weighted retained on sieve)					
Sawdust-amended media						
J	11.7	30.6	21.3	24.2	12.2	.73
D	14.3	25.7	24.4	22.4	13.2	.67
F	3.6	21.1	27.6	28.2	19.5	.33
Vermiculite and perlite-amended media						
A	7.4	23.8	22.8	28.4	17.6	.45
Hydrophobic rockwool-amended media						
H	2.5	30.3	20.7	26.9	19.6	.49
M	9.8	15.9	20.8	31.7	21.8	.35
L	5.7	17.5	19.1	32.5	25.2	.30
C	11.7	10.6	21.2	35.1	21.4	.29
Pure peat media						
K	13.0	13.1	22.1	33.7	18.1	.35
Vermiculite-amended media						
I	7.3	19.3	24.7	33.1	15.6	.36
E	2.2	22.7	18.9	34.1	22.1	.33
B	5.9	16.7	21.7	37.7	18.0	.29
Hydrophilic rockwool-amended media						
G	1.6	19.0	18.1	34.4	26.9	.26

Media. -- Predictably, variable ingredients yield variable media. In many instances the physical and chemical effects of amendments on the media are confounded by peat and nursery differences. This confusion limits the ability to make critical comparisons among the media but allows an appreciation of the range of cultural conditions under which the same crop is being grown.

The chemical properties (Table 7) display a wide range of values. The EC values are particularly high reflecting the presence of slow-release fertilizers or recent irrigation with nutrient solution. The rockwool amended media had the highest pH. Media pH were ranked similar to ranking of the amendments.

On a wet-sieve basis, media particle size analysis displayed less variability than the unamended peats (Table 8). The C:F ratios from wet sieve analysis are consistently less than the dry sieve analysis. The sawdust-amended media had the largest coarse:fine ratios, with the medium prepared with the finer sawdust having a much smaller C:F ratio.

Water retention results (Table 9) indicate substantial differences in saturation water content. Values given for rockwool-amended media were difficult to obtain because the media did not wet readily. Bulk densities vary more than unamended peats as do the effective porosities. These differences reflect a nursery-effect in mixing and loading media.

On average the sawdust amended media have the largest aeration porosities. The vermiculite amended media had the lowest aeration porosities. There did not appear to be a relation between the C:F ratio of the media and the aeration porosity.

Watering regimes. -- It was assumed that media were maintained at low soil water tensions throughout the growing season. However, gravimetric sampling indicated a range of watering regimes. Some nurseries were irrigating media at soil water tensions less than 0.06 bars, others at tensions greater than 0.33 bars - outside the range for which water retention curves were developed.

Table 9.--Media water retention analysis. Results expressed on a volumetric basis. Media arrange in decreasing aeration porosity (AIR).

	Water tension (bars)							
#	0.00	0.03	0.06	0.10	0.33	AIR	BD	PORE
Sawdust-amended media								
F	84.6	45.9	38.0	31.7	25.4	38.7	.131	91.2
J	80.4	53.6	44.2	36.5	29.8	26.8	.121	91.1
D	78.6	57.6	45.6	36.8	29.5	21.0	.136	90.9
Hydrophobic rockwool-amended media								
C	81.9	49.0	39.3	32.6	27.8	32.9	.120	92.9
L	75.3	48.6	39.1	32.6	27.3	26.7	.183	90.5
M	82.3	55.7	46.2	39.3	32.6	26.6	.135	91.3
H	48.7	27.2	22.6	19.2	17.3	21.5	.202	90.8
Hydrophilic rockwool-amended media								
G	66.3	40.2	31.6	26.3	22.2	26.1	.223	89.6
Pure peat media								
K	85.7	61.6	53.3	44.5	35.9	24.1	.117	91.5
Vermiculite-amended media								
E	78.7	52.3	45.6	40.8	34.4	26.4	.126	93.3
B	79.1	56.0	46.8	39.7	32.3	23.1	.117	92.8
I	75.4	54.0	42.9	35.7	29.7	21.4	.111	92.7
Vermiculite and perlite-amended media								
A	75.9	57.7	48.5	40.0	30.1	18.2	.131	92.4

AIR - aeration porosity (% volume)
BD - bulk density (g/cc)
PORE - effective porosity (% volume)

SUMMARY

The physical and chemical properties of peat and amendments are highly variable. Combined, these ingredients produce a wide range of media. The variability of media must be recognized in cultural management.

There is are advantages and a freedom in mixing one's own growth media. Along with this freedom comes the responsibility to recognize and alter the crop culture to accommodate the properties of the media.

Alternative nursery media must be examined for physical and chemical properties. If mis-managed, even the ideal medium may not be capable of yielding a healthy, acceptable crop.

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The "Izing" of British Columbia Nurseries[1]

I.D.M. Armit[2]

INTRODUCTION

It has been 12 years since the Western Forest Nursery Council held the 1976 Conference in British Columbia, at Surrey. It is a little over two years since I approached the Ministry of Forests Executive with the proposal that we co-host the 1988 meeting in Vernon, B.C., and requested authorization for Ralph Huber to travel to the United States to extend the invitation to our sister associations, so that all the planning, preparation and organization that is essential for a successful conference could commence.

Since I expected to retire in early 1990, I had anticipated that the 1988 Conference would be the last I would be attending as Manager of Provincial Nurseries. I was looking forward to this meeting as the cap-stone event in my career as Nursery Manager, providing me with the opportunity and the forum to wax eloquent about all the marvelous improvements we achieved during those 12 years, in nursery techniques, in quality of stock produced, in economic efficiencies, etc., etc.

I did not anticipate that the mad rush of events and changes during the first 10 years would actually accelerate in the next two years. The winds of change in fundamental forest management policy in British Columbia have not only dramatically altered the landscape of forest nursery practices and responsibilities for reforestation, but left the writer on sidelines, prematurely retired, no more than an interested spectator to the latest developments in "Fantastic Land".

CONTAINERIZATION

In 1970, seedling production was approximately 55 million seedlings, all basically field grown bareroot seedlings, with a few transplants and a test program of containerized seedlings. By the time of the 1976 Conference in Surrey, the Province of British Columbia was growing 80 million seedlings annually, all in nine Ministry of Forests Nurseries, 20 million container-type seedlings and 60 million bareroot seedlings, including 8 million transplants. The program of seedling production in provincial ministry nurseries peaked in 1980, at 105 million seedlings, consisting of 75 million bareroot seedlings and 35 million container-type seedlings. Since then, the Ministry nursery program has remained about 100 million seedlings annually but the ratio of container-type seedlings to bareroot seedlings has been reversed to 70 percent containers and 30 percent bareroot. Since 1980, all program increases have been achieved in private sector nurseries, which in 1988 had risen to more than 135 million trees. Except for 7-8 million bareroot seedlings being grown in one licensee nursery, all are container-type seedlings. Consequently, the total provincial program annually is now about 237 million trees, of which 200 million are container-type stocks.

Further, a rapid increase in large bareroot transplant stock which reached over 30 million by 1984, with a market demand for over 50 million, has been replaced by large two-year container stock types, particularly for hot lift and summer outplanting. As a consequence, the production of bareroot transplant stock types has dropped back to around 5-6 million annually and should drop even lower in the next two years.

COMMERCIALIZATION

Until 1980, all seedling production for reforestation on Crown Land was produced in Ministry nurseries. In 1976, the Pearse Royal Commission report on forestry issues in B.C. was tabled. Among its many recommendations and conclusions was the finding that there did not seem to be any good reason to continue the policy of excluding private nurseries from the opportunity to produce seedlings for Crown Land reforestation. Subsequent to the Royal Commission report, a task group chaired by the writer was formed with a mandate to investigate and prepare a white paper on the potential for

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[1] Paper presented at the combined meeting of the Western Forest Nursery Council and the Forest Nursery Association of British Columbia, Vernon, B.C., August 8-11, 1988.

[2] I.D.M. Armit, retired, former Manager of Nurseries, Silviculture Branch, Ministry of Forests, Victoria, B.C.

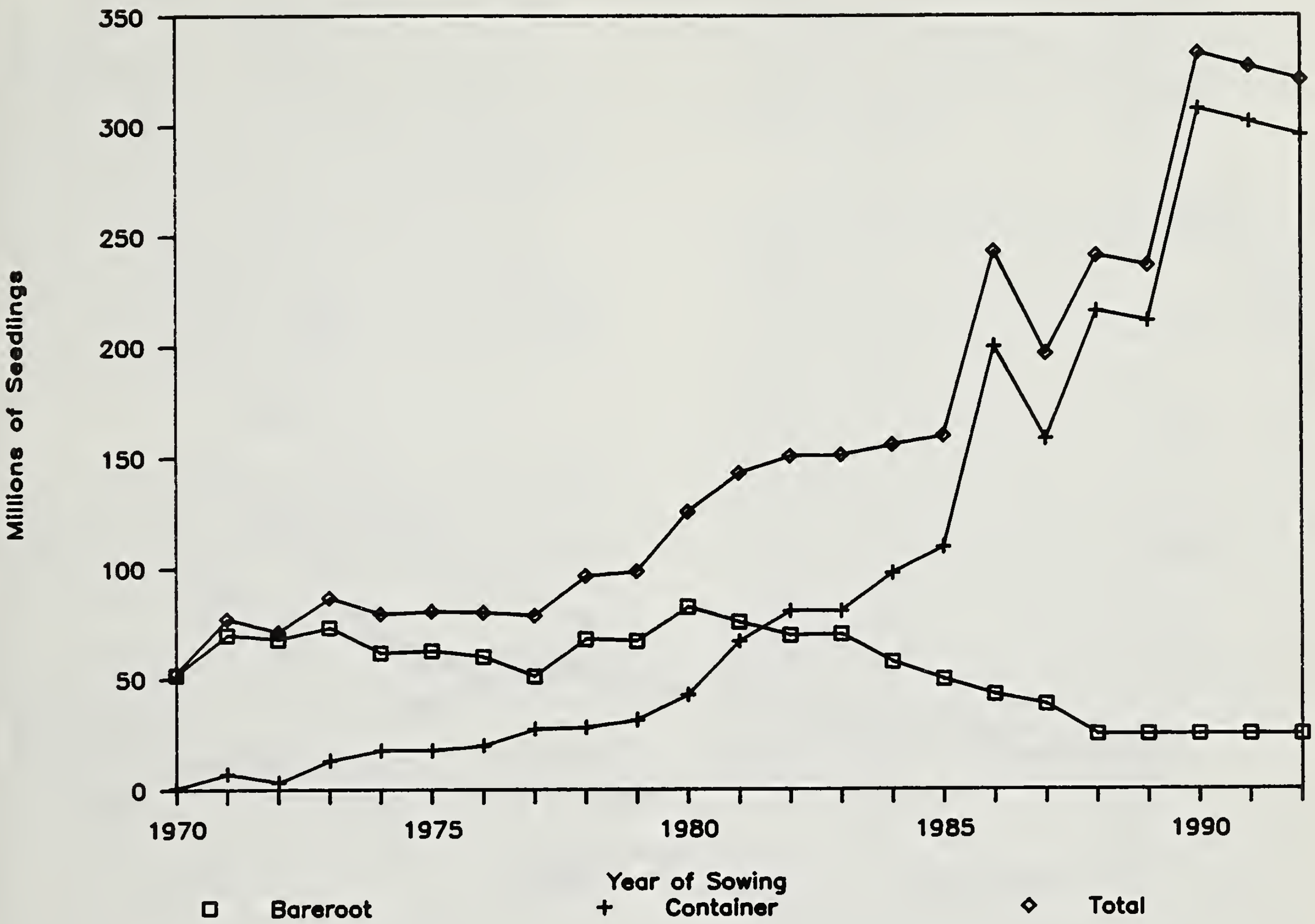

Figure 1.--Nursery production, bareroot and container, showing millions of seedlings sown for from 1970 and anticipated production to 1992.

private sector participation in such tree seedling production.

Among the more significant conclusions reached by the task group, subsequently endorsed by both the Ministry of Forests Executive and by the government, were (1) that the five and ten year targets for expanding seedling production in the 1980's could only be achieved by private sector participation, due to the staffing and capital cost constraints on government facilities; (2) that the Ministry of Forests nursery production should be capped at around 100 million seedlings annually, with future emphasis to be placed on conversion from bareroot to container stock types, to satisfy existing demands; (3) that all future increases in seedling production for Crown Land reforestation requirements should be directed to private sector nurseries through appropriate contractual arrangements.

From this policy, the Forest Nursery Association of British Columbia was eventually born. Private nursery production started in 1980 with 8.8 million seedlings being sown for, rising to more than 135 million seedlings in 1988, produced in six licensee and over 25 commercial nurseries. The reforestation program which will approach 240 million trees in total in 1989, is expected to peak under present management criteria at about 325 million in 1991-92. By this time, all but 30 million trees will be produced in private nurseries, and all but possibly 20-25 million, are expected to be container stock types.

COMPUTERIZING

Almost hand in hand with the phenomenon of containerization and commercialization was the development of computerization.

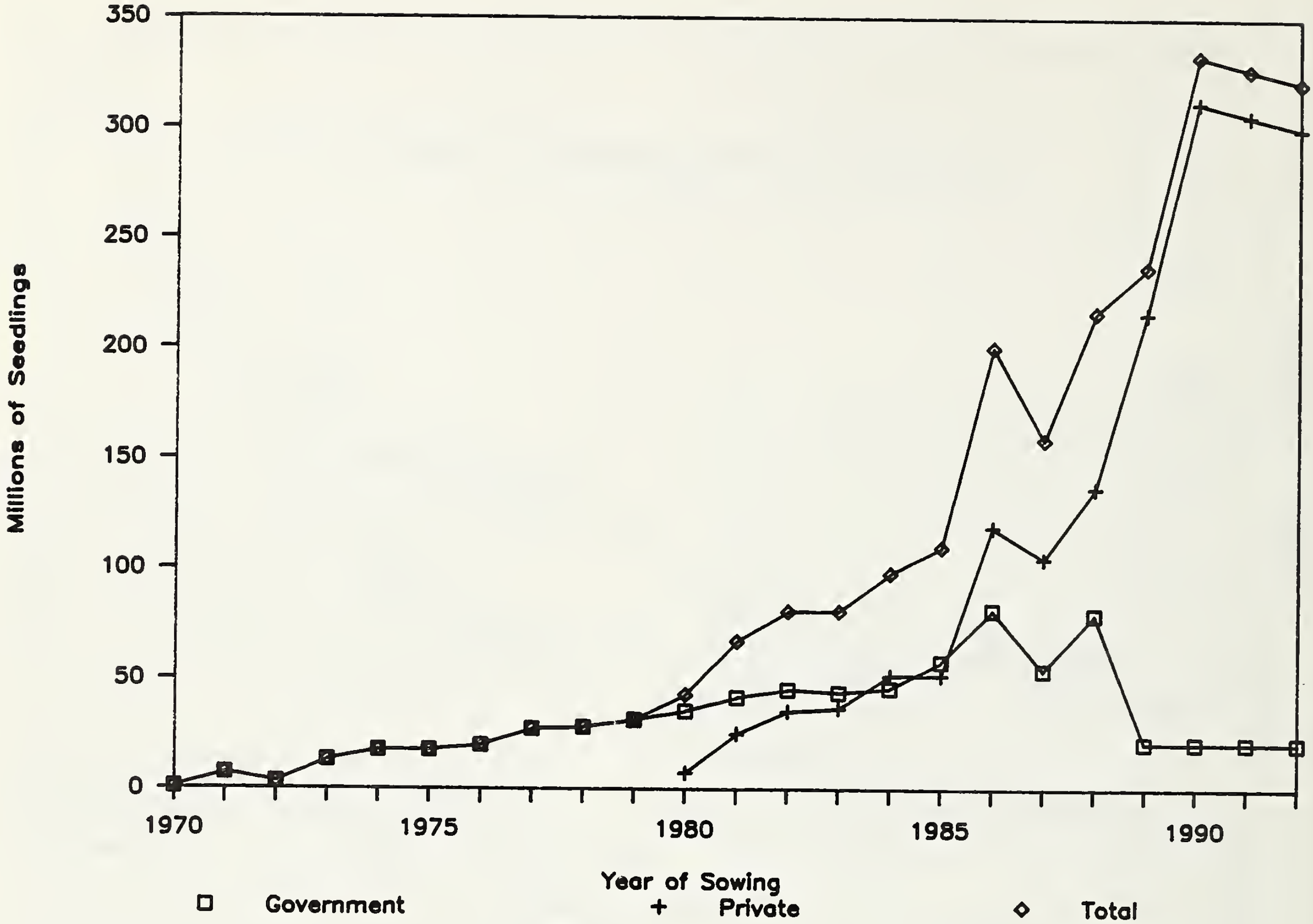

Figure 2.--Container production showing millions of seedlings sown for from 1970 and anticipated production to 1992.

Computers were introduced into operational nursery management activity in 1979, basically to rapidly process thousands of sowing requests into numerous nurseries, consistent with their growing capacities, contractual obligations and stock type capabilities.

Prior to the introduction of computers for this purpose, sowing request allocation procedures required manual processing that took 2-3 months to complete. It was the principal bottleneck to prompt withdrawal and preparation of seed for early spring sowing. As we gained experience, modified our management time-lines and made our computer programs more sensitive to our needs, the lead time from receipt of sowing request to sowing allocation was reduced from months to weeks to days, and finally, same-day turnaround of individual request data by nursery is now achievable.

Computers were initially introduced as an operational management tool to "crunch numbers". As they became more versatile, more sophisticated, and less expensive, they became tools for quality control technicians and biologists to track seedling performance and monitor the interactive processes of environment and seedling development; they enable the operational technician to modify that biological environment to optimize development in accord with the biologists' recommendations. Fully automated environmental control systems with computer managed biofeedback are operational realities.

More recently, with network hardlines and integration of programs, the same computer systems are giving higher management and executives a direct window and immediate access to all on-site operational information, to the same information and timeline used by the on-site technicians. There are no secrets anymore.

Data can no longer be winnowed, interpreted, held in reserve or screened through several levels of management over extended periods of weeks or months. Management can make its own decision as to what is relevant or extraneous, on a real time basis. Middle level management becomes increasingly superfluous to the decision-making process - fewer people on fewer levels are needed to keep the process functionally viable; management level "downsizing" becomes another feasible option. Computers are excellent tools for operational activities in nurseries; they are also excellent tools for strategic management decisions; they may prove to be the nemesis for most mid-management people.

DOWNSIZING

In every year since 1981, there has been a decrease in the manpower resources allocated to Ministry nursery operations. Some years the decrease has been small, 3-5 percent; some years it has been large - over 20 percent, but every year fewer resources.

Innovative techniques had to be implemented to offset this reduction, including contracting out of work, use of piece work incentives, reduction or elimination of ancillary services, and transfer of responsibilities to the private sector. In 1988 we have the ultimate form of downsizing. The conversion of all but two of the eleven Ministry nurseries to private ownership, with the closure of any facility which does not prove to be an economical viable entity in the private market place. A further 177 man years of nursery labour and technical staff, headquarters administration, and specialized extension services will be eliminated, over 60 percent of current Ministry nursery services staff levels, a significant downsizing to anyone's standard.

PRIVATIZING

It is not my intent to explore the issue of competition between or the relative efficiency of government versus private nurseries. Thomas Landis presented an excellent paper on that subject at the Intermountain Nursery Association meeting in Oklahoma last year. All of his definitions and most of his commentary are relevant to the experience in British Columbia.

The single major distinction is that, in B.C., the Crown owns 95 percent of the forest land base. Until September 1987, our policy was that the landowner (i.e., the Crown) was ultimately responsible for the cost of reforestation, regardless of who managed or harvested the trees under license.

Under that philosophy, the Crown supplied planting stock for all reforestation on its lands at no cost to the licensee. From 1928 to 1979, such stock was only produced in nurseries operated by the Crown. From 1980 to 1987, as I previously indicated, private nurseries were encouraged to participate in seedling production for Crown land reforestation under appropriate contractual agreements; the Crown continued to supply such stock at no cost to the licensee until this year.

A major policy change - one could almost say revolutionary change, since it discarded a policy that had stood for 60 years - occurred in September 1987. The government, with supporting legislation, made the licensees solely responsible for all costs of silviculture, including costs of reforestation and planting stock on all areas harvested by forest licensees after October 1, 1987. This policy change effectively shifted the burden from the Crown to the licensees. It also freed the licensees to spend their money as they saw fit to achieve the silviculture objectives set out in their approved pre-harvest silviculture prescriptions. In reforestation work, this meant they could grow their trees in their own nursery, buy them, or contract to have them grown in a commercial nursery of their own choosing. They could also purchase or order them from a Ministry facility; however, this last option was discouraged except where bareroot seedlings or speciality container-transplant stocks were required, since the Ministry was initiating the parallel process of privatizing Ministry nurseries.

The major shift in policy meant that total Ministry capacity would, within five years, exceed the Ministry's internal need for seedlings to reforest on forest lands which were not licensee responsibility (such as wild fire and small business program harvest areas still managed by the Crown). The incentive was thereby created to either privatize or close most of the Ministry nursery capacity, preferably while economically viable units could be incorporated into the expending private sector market for tree seedlings.

Consequently, one nursery has already been sold, six more are scheduled to be transferred to private ownership within the next month or so to a consortium led by Charlie Johnson, past Director of our Silviculture Branch. Two more nurseries will likely be on the market in early 1989, or will be designated for alternate land use. Only two nurseries, Surrey and Skimikin, will remain to provide some of the Ministry's internal requirements for reforestation on Crown owned and managed forest lands, and to permit continued experimentation with new nursery techniques, improvements in technology and automation.

The Government of British Columbia provided generous early retirement packages which not only facilitated the process of staff downsizing but removed, by volunteer decision, most of the middle and senior management people who might have most resisted the proposed changes in policy. The Government facilitated the process

of employee participation in the purchase of privatized facilities by freely providing financial and business planning services to develop the required proposals.

The Government passed Draconian legislation that forced the transfer of responsibility for reforestation to the forestry industry, but it then eased the impact by providing a 5 year phasing-over period for implementation. By judicious use of such measures as honey to sweeten the medicine, the Government of British Columbia achieved its triple objective of privatization, downsizing and transfer of responsibilities to the private sector with a minimum of disruption, employee dissension or public resistance to the radical changes in government policies.

The triple-edged sword of privatization, early retirement incentive plans, and radical changes in Forest Service policy on silviculture has changed the world within which Ministry nurseries function and the role which they will be expected to play in future, whether operated as public or private businesses.

MECHANIZING AND AUTOMIZING

From the mid 1960's when seedling production first was increased in a major way through to the present time, a critical emphasis has been to keep costs and manpower requirements in check, by increased mechanization, automation, and employee productivity.

In bareroot sowing, we went from manual broadcast sowing to random drill sowing to species-specific precision sowing standards with specialized seeders. We went from manual lift to Grayco lifters to Fobro lifters to integrated lifter-combines with large bin trailer processing, in association with cold-storage-sorting area complexes. We solved the problems of lateral pruning with species-specific procedures; and were working to operational solve the problem of cross-bed pruning in bareroot seed beds. However, even faster than we improved our techniques for bareroot seedling production, we were converting to container-seedling production. The opportunities for cost and labour savings by automation and mechanization were even greater. Productivity per employee was much higher and improvements were easier to achieve.

We have already begun development of a prototype automatic extraction machine for container-type seedlings. I confidently expect we will see a fully automated container processing line in operational use within three years, capable of extraction, grading, counting, bundling, wrapping and packaging into cartons as a single integrated operation, with only one or two people required to process 10 million seedlings.

THE NEXT DECADE

What are my other predictions for the next 10-12 years? Based on the past 12 years experience, my first prediction is that almost all the other predictions I make will be wrong.

I believe we may have too many eggs in one basket with the current overwhelming reliance on container-stock types. The potential for biological and environmental disaster is extreme in a system that lacks buffer or resilience to adverse influences. A return to significant production of large bareroot or container-transplant stock types seems a reasonable possibility, particularly on sites where prompt establishment of "free growing" plantations is essential for planned rotational growth.

The monopolistic nature of material supplies in container production should be of real concern to all seedling producers - investigation of alternative suitable growing mediums and cost-competitive container structures should be given high priority.

I believe we will also see a major increase in use of local nursery seedling production for hot lift planting in all seasons, avoiding the need for cold storage or long-distance transport logistical planning. The emergence of large 3 to 4 year old planting stock for crop-tree establishment may prove to be a viable economic option in concert with local nursery utilization, along with pre-conditioning of stock prior to shipment to the planting site.

I am sure that forest management firms, freed from the "dead hand" of government, are going to come up with innovative concepts in silviculture and reforestation, perhaps even invalidating the current high reliance on reforestation with nursery grown planting stock, to achieve the objective of "free growing" plantations for which they are responsible to achieve in their approved silviculture plans.

I believe the next decade will see the further development and strengthening of a healthy viable private nursery industry with competent management and technical staff producing superior quality planting stock to meet the site-specific requirements demanded by the forest industry. I believe there will also be a winnowing out of some "weak" nursery operations due to the pressures of competition or the unplanned risks of environmental disasters with which private enterprises unhappily must contend. I believe there will be development of horizontally integrated companies providing all silvicultural services from cone collection, seed processing, seedling production, planting to plantation maintenance, in the same manner that contract loggers provide "stump to dump" services for the large forest companies.

For those who can stay the course, there will be rewards, both financially and in

personal satisfactions. This is a great business to be in, even when the greenhouse gets too dammed hot.

In conclusion, there may be meaning to that strange topic phrase "the Izing of Privatization", if the word is spelled I-c-i-n-g. The newest consortium of entrepreneurs operating privatized government nurseries reputedly have outstanding managerial, technical and operational capabilities.

If they are as efficient, technically competent, and informed on all biological issues of seedling production and quality control as they have indicated to the present commercial nurserymen, then the "icing of privatization" will be the incredibly profitable nursery operations they will establish, and the wealth they will individually and collectively accumulate in the years to come by being successful entrepreneurs, to the betterment of all of us residing in British Columbia, depending on the forest resources for our livelihood.

Managing Nursery Information in the 1980's[1]

Michael Pelchat[2]

Faced with a rapidly expanding reforestation program and an outdated manual record keeping system, the British Columbia Ministry of Forests developed a Nursery Information System to manage information on seedling production and distribution. A brief description of the system is presented.

INTRODUCTION

Seedling production in British Columbia went through a period of rapid expansion during the last two decades. The number of seedlings planted in B.C. rose from 26 million in 1969, to 63 million in 1979, and to almost 200 million seedlings in 1987 as shown in Figure 1. This rapid expansion of the reforestation program prompted the Ministry of Forests to review the process of nursery information management in the fall of 1982. The aim was to develop an information system which would cope with the expanding seedling production program, and provide dependable reporting capabilities.

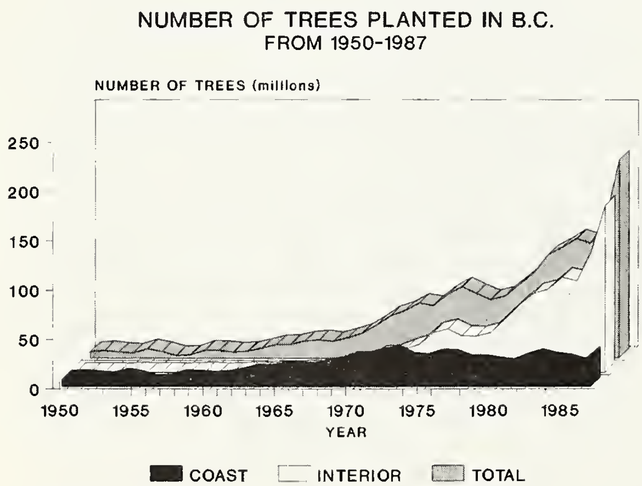

Figure 1. Number of Trees Planted in B.C.

The Problem

The record-keeping system in use in 1982 was a manual file card system which provided a few simple summary and detailed reports. This manual system had two major deficiencies. The first was an inability to reconcile the number of seedlings shipped for planting and the number of seedlings actually recorded as planted. In 1981 this difference in seedling numbers produced a "paper loss" gap approaching 10 per cent, and this was expected to get worse as the planting program expanded. The second was the limited number of reports that were manually compiled from the file cards. Any additional reports demanded by forest managers required a large amount of time and effort to produce. Recent advances in information management had raised the information expectations of both the nursery managers and the field foresters, and they were anxious to see this technology applied to seedling information. Thus, it was obvious that the manual system would not cope with the information needs of a rapidly expanding seedling production program, and that some form of computerized information management system was needed to maintain control.

The Ministry of Forests had already utilized computers to assist with the management of the reforestation program. The ordering of seedlings was being handled by a Sowing Request System which assisted in matching the orders from field foresters for seedlings, called sowing requests, with the various government and privately owned nurseries and ensured that forest tree seed and nursery materials arrived at the assigned nurseries at the proper time. A Planting Report System was also under development to capture and report on information related to the annual planting program. The next step was to develop a system to bridge the gap between these two activities and provide the field foresters with information on their seedlings while the stock was being grown in the nurseries and subsequently transported to the planting sites.

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[1] Paper presented at the Western Forest Nursery Association Meeting, Vernon, B.C. August 8-11, 1988.

[2] Michael Pelchat is Nursery Operations Planning Officer, Ministry of Forests, Victoria, B.C., Canada.

The Solution

In the fall of 1982 approval was given to investigate the feasibility of producing a system to manage nursery information. Over the next two years, the existing manual system was evaluated and a proposed Nursery Information System was described. The development of the new system was initiated in the fall of 1984.

The Nursery Information System was to provide an integrated information system to the various agencies involved in reforestation while reducing the overall manual paperflow process of compiling, transcribing, and reporting nursery information. The main objective was to be able to track a sowing request from inception, through the growing cycle in the nursery, to the dispatch of seedlings to the field forester at the planting location. Development of the system was done in phases, with each phase tested in at least two different nursery sites prior to implementation on a province wide basis. The first phase, dealing with inventories and seedling quality, was operational in the spring of 1986, while the seedling storage and distribution phase of the system was operational in the summer of 1987.

The System

The Nursery Information System is a data management system composed of a central system located on a mini-computer at the Headquarters office, and local systems located on personal computers at each automated nursery site and each Nursery Zone Administrative Office as shown in Figure 2.

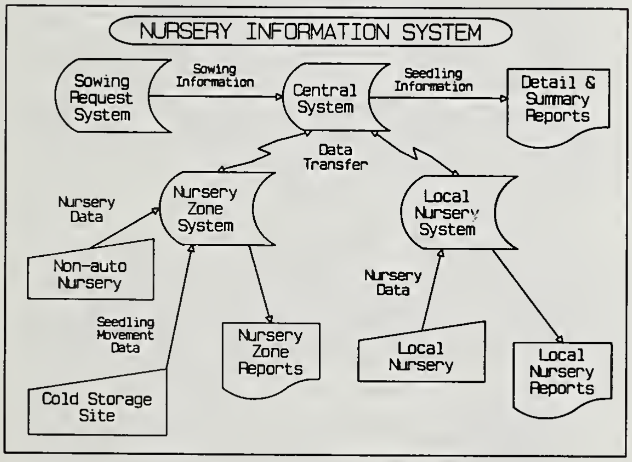

Figure 2. Nursery Information System

The main function of the central system is to receive data from the local sites in the province and update a central database which is then used to produce detailed and summary reports for distribution to the various agencies involved in reforestation, and to the B.C. Forest Service managers and executive officers. A central database is required to handle the complex relationship between nurseries and their clients. At any time a client may have seedlings being grown at several nurseries to take advantage of each grower's expertise with a particular species or stock type. As well, each nursery may be producing seedlings for more than one client. The only way to provide the clients with a report containing all their seedlings is to gather all the data together at one time.

There are three subsystems which make up the local Nursery Information System. These are the Nursery Growing Subsystem, the Quality Control Subsystem, and the Storage and Distribution Subsystem.

The Nursery Growing Subsystem, represented in Figure 3, manages the bulk of the seedling information. The main purpose of this subsystem is to process and report on information pertaining to growth progress, seedling quality, inventory estimation, cultural treatments, and transplant and lift scheduling for all seedling stock from the sowing phase to shipping of these seedlings. The subsystem operates as an online system with local reporting and screen display functions at the nursery sites. Data processing is done throughout the day, and data transfer to the central computer is accomplished electronically over phone lines during the night. A reduced version of this subsystem is also available at the Nursery Zone Administrative Offices to record inventory estimations and pesticide information from nurseries with no local online processor.

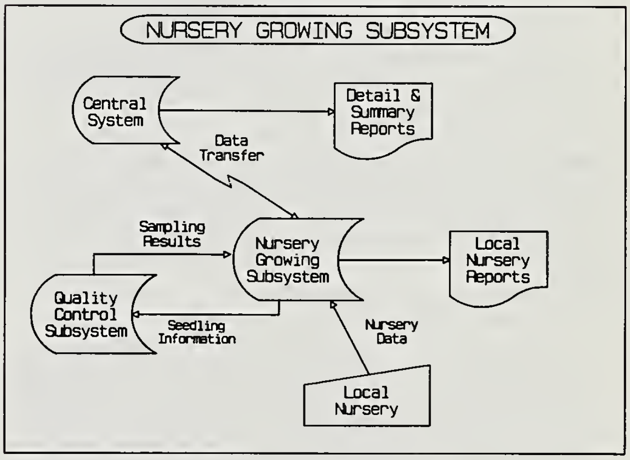

Figure 3. Nursery Growing Subsystem

The Quality Control Subsystem, represented in Figure 4, which assists the nursery technicians with data analysis of seedling information. This subsystem is only available at the nursery sites with local processing capabilities. To estimate inventories and determine seedling quality throughout the growing period, seedling growth status and trends are sampled, measured, statistically analyzed, and reported. The separation of

quality control data from the nursery growing data allows the technicians to sample and analyze seedling data repeatedly and use only those results which they are satisfied with to update the Nursery Growing Subsystem information. This computer aided analysis provides the nurseries and their clients with the ability to modify culling standards and evaluate the impact on the estimates of inventory in order to attain planting priorities. Based on these estimates the field foresters can plan their planting program and define specific shipments for specific sowing requests. This subsystem also records the cultural treatments applied to the crops while the crops are at the nurseries.

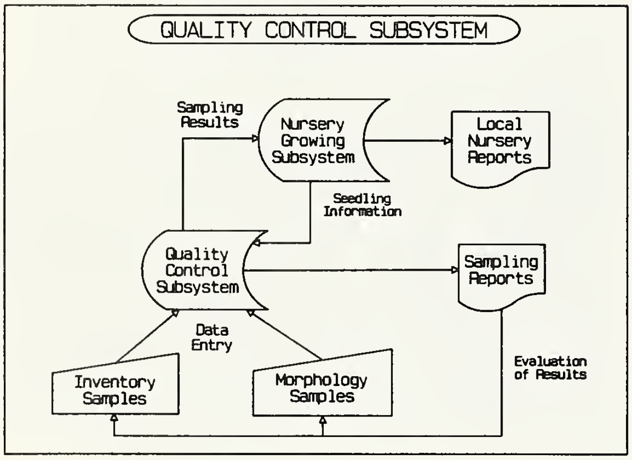

Figure 4. Quality Control Subsystem

The Storage and Distribution Subsystem, represented in Figure 5, is used to coordinate the storage and distribution of seedlings prior to and during the planting season. This subsystem provides the online nursery sites with seedling storage and shipping management functions. Once seedlings are shipped from the nurseries, the management responsibility transfers to the Nursery Zone Administrative Office where a local online version of this subsystem is used to manage seedling movement and storage within the nursery zone.

Shipping can be initiated by a pre-arranged schedule submitted prior to lifting, or via telephone instructions from the field foresters during the planting season. A multicopy Shipping Order/Invoice is utilized to monitor seedling movement from the nurseries to the planting sites. The information on the stock being issued is recorded by the shipper and a copy of the invoice is sent to the local Nursery Administrative Office where the data is entered into the system. The remaining copies are sent with the seedling shipment. At the destination the field forester confirms the amount of stock received and another copy of the invoice with the receipt information is sent to the local Nursery Administrative Office for data entry. This process of matching stock issues and receipts provides stock movement and storage monitoring, regardless of how many times the seedlings are moved, as well as the ability to reconcile stock shipped by the nurseries with stock received by the designated final receiver.

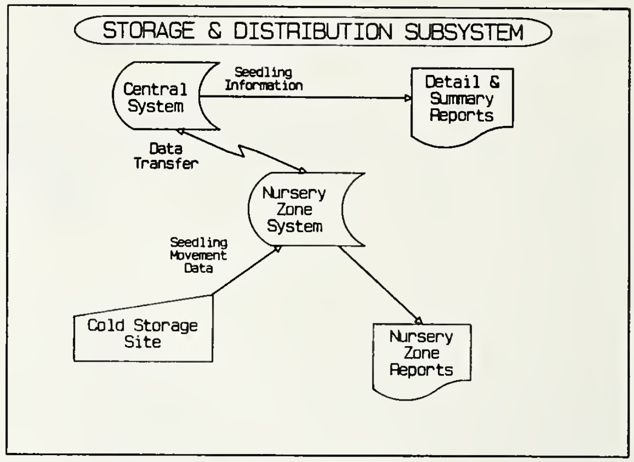

Figure 5. Storage & Distribution Subsystem

Retrospect

The development of an information system to manage the production of over 200 million seedlings was a major undertaking, requiring close cooperation between the users of the system and the programming staff over the five years that the system was developed and implemented. Even with this close cooperation, a large portion of the time and effort was devoted to maintaining and enhancing the system in response to feedback from the users, and changes to government legislation and forest policy. Overall, the system has met the stated objectives and the users have been satisfied with the results. Everyone involved has agreed that the previous manual system would not have been able to cope with the expansion of the seedling production program.

Providing an accurate information system while maintaining the flexibility needed to manage a biological product was a formidable challenge. Of the many lessons learned from the development of this system three stand out as critical to the success of the system:

1. Involve the users from the very beginning.
2. Accurately describe the requirements of the new system.
3. Start small, having a solid foundation of basic functions will provide the necessary support for the additional functions which will be required as the system matures.

Agencies and individuals desiring further information on this system are invited to contact the author.

2-15

Cumulative Trauma Disorders in Forest Nursery Workers[1]

Ulrika Wallersteiner[2]

Abstract - This study focused on the upper limb injuries suffered by up to 31% of seasonal nursery workers in British Columbia nurseries. Problems occured primarily in right hand flexors and both shoulders; subjects with no first aid problems were slightly older, had more work experience, and used the neutral hand position more frequently when working.Recommendations include training, rest breaks, maintenance of constant workplace temperature, and the purchase of sit-stand stools.

INTRODUCTION

Logging is one of the major industries in Canada. In order to ensure logging in the future, Canada has an intensive reforestation program, though many feel it is not sufficient. Part of the problem is associated with the occupational health problems experienced by many sorters.

In British Columbia, government nurseries plant and harvest more than 110 million seedlings per year. This represents approximately 50% of the total seedlings raised for reforestation. These nurseries employ approximately 800 workers at the peak of the sorting season. In 1985, 33 Workers Compensation claims involving upper limb injuries to sorters were filed, resulting in 689 lost work days, direct costs of $28,000, and estimated indirect costs of $112,000.

The workers' jobs in the nurseries are very manual intensive, requiring no tools other than the worker's two hands. In the early months of each year, seedlings are lifted from the ground and stored in cold rooms to inhibit their growth. Boxes of chilled seedlings are distributed daily to sorters in a sorting shed, who sit on a stool or stand at a flat work surface. Sorters wearing rubber gloves for protection from chemicals separate the seedlings, using the index or middle finger from the dominant hand to pull while holding the entangled bundle in the other hand. The separated seedlings are sorted or graded into groups suitable for reforestation planting or for discard. Sorters sort approximately 6000-7000 seedlings per day. Bundles of sorted seedlings are placed on a conveyor belt and are transported to a wrapper who packages them in cellophane and chops off trailing roots.

The management of the occupational health problems of nursery workers is made difficult by several factors:

1) The time period for lifting and sorting the seedlings changes from year to year and cannot be determined more than a week or two in advance.

2) Sorting crews consist of both experienced and inexperienced workers.

3) Most ergonomic studies relating to upper limb disorders focus on redesign of hand tools, which are not used in this situation.

METHODS

To assess the extent of the occupational health problems experienced by nursery workers, a questionnaire was developed and distributed at the end of the sorting season to three nurseries and also to head office staff (for control). Approximately 500 subjects were surveyed. Workplace factors were assessed through the questionnaire and by measuring the dimensions of the workstations.

First aid reports gathered during the sorting season were assessed to identify the most common areas of injury and the types of injuries experienced. In addition, all upper limb musculo-skeletal injuries were more accurately defined by having the person affected shade in areas on a body diagram.

Because of the numerous hand manipulations performed during a shift, certain hand motions are believed to contribute to the health problem. Ten tree sorters (five healthy and five infirm) were viedotaped. Eighty hand motions per subject were analyzed in 0.5 second intervals. The shoulder, elbow and wrist joints were reported in either a neutral, flexed, or extended position. Hand deviation was reported either as ulnar, radial, or neutral.

RESULTS

Of the 500 questionnaires distributed, 447 nursery questionnaires and 17 office questionnaires were returned. All subjects reporting arthritis or fractures in the upper limb body parts were removed from the study group, thus eliminating 100 subjects. Responses were then analyzed according to work location, job category, and reporting or

1. Paper presented at the Western Forest Nursery Association Meeting (Vernon, British Columbia, August 8-11, 1988).

2. Ulrika Wallersteiner is Principal Ergonomist of Ergo Systems Canada Inc., Toronto, Ontario and West Vancouver, British Columbia.

non-reporting of hand problems. The resulting subject group totalled 275, with 118 reporting hand problems and 157 having no hand problems. By analyzing certain questionnaire responses using this breakdown, and using the non-parametric z-test, an attempt was made to determine why certain workers experience problems and some do not.

Table I shows that healthy subjects were slightly older and had more work experience as sorters and wrappers, while Table II indicates that infirm subjects consistently experienced significantly ($p<0.05$) more right, bilateral, and frequent hand and shoulder problems.

Table I. -- Characteristics of Healthy and Infirm Subjects.

	Infirm		Healthy	
	Mean	SD	Mean	SD
Years Worked	4.9	3.6	5.2	4.7
Weeks Worked	11.4	7.6	12.2	9.7
Age	35.8	10.1	37.4	11.8
Height	65.0	2.5	64.7	3.1

SD=standard deviation

Table II. -- Distribution of Hand and Shoulder Complaints

	Infirm	Healthy
Hand Discomfort		
Right	43 (36)	
Left	14 (12)	
Both	60 (51)	
Shoulder Discomfort		
Right*	21 (18)	14 (9)
Left	5 (4)	3 (2)
Both*	40 (34)	28 (18)

* = significant ($p<0.05$)
Numbers in brackets represent percentages.

Infirm subjects experienced tiredness, stiff shoulders, headaches, and lower back pain more frequently than healthy subjects, but only the occurence of stiff shoulders was significantly higher. Infirm subjects experienced significantly more pain at the beginning of the sorting season, though both groups experienced more discomfort at the beginning of the season than at the end. Prior work did not seem to affect the distribution or the onset of problems.

The subject groups did not differ with respect to sorting and holding hand preferences. About 60% of workers used the right hand for sorting, while only 13% used the left hand and 12% change hands. Both groups had comparable hand preference distributions; the majority were right handed and 8% were ambidextrous. However, infirm subjects did experience significantly more problems in their hands while wrapping. And, although both groups wear glove liners, a significantly larger proportion of infirm subjects experienced cold hands and muscle fatigue. Table III details workstation problems.

Table III. -- Workstation Problems

	Infirm	Healthy
Lighting		
Too High	9 (8)	10 (6)
Too Low	14 (12)	29 (18)
Working Posture		
Sitting	13 (11)	18 (11)
Standing	58 (49)	72 (46)
Both	46 (39)	65 (41)
Table Height		
Too High	4 (3)	9 (6)
Too Low	36 (31)	32 (20)
Worksurface		
Too Large	0	1 (1)
Too Small	38 (32)	55 (35)

Video analysis showed that workers experiencing health problems tended to deviate more frequently from the anatomically neutral position of the upper joints.

DISCUSSION AND RECOMMENDATIONS

Nursery workers are unique compared to other industrial workers in that they do not use any hand tools, they are seasonal workers, and the group of workers at the beginning of a season is usually a mixture of experienced and inexperienced workers. Additionally, the inability to predict when lifting and sorting will be done makes it difficult to establish an exercise program.

Occupational health problems in sorters are specific to the right wrist flexors, index and middle fingers, the right and left shoulders, and upper back areas. Infirm subjects are weaker in hand and finger strength at the beginning of the sorting season, deviate more frequently from the anatomically neutral upper joint position, and feel colder throughout the day comapred to healthy subjects. Infirm subjects also feel that their workstations are too low.

The following three recommendations were developed:

1) A video training program should be used to assist crew leaders in training sorters. The video should emphasize good work methods and proper hand motions.

2) An exercise-gymnastic rest/pause program should be introduced. Exercises should use resistance (such as rubber tubing or hand squeezing) to develop upper limb strength.

3) Administrative controls should be applied to keep the sorting sheds warmer.

245

A Stock Quality Assessment Procedure for Characterizing Nursery-Grown Seedlings[1]

S.C. Grossnickle, J.T. Arnott and J.E. Major[2]

Abstract.--Western hemlock and western red cedar seedlings were grown in a container greenhouse system under four different nursery cultural treatments. A stock quality assessment procedure was developed to characterize a seedling's drought avoidance (i.e. needle and root surface area, needle resistance, root growth capacity), drought tolerance (i.e. osmotic potential) and cold tolerance (i.e. frost hardiness, low temperature root growth capacity) capabilities developed through the various nursery cultural treatments. Results showed western hemlock seedlings in the short-day treatments and western red cedar seedlings in the moisture stress treatments had the best stock performance potential characteristics.

INTRODUCTION

Reforestation success depends largely on matching proper seedling stocktypes with field site conditions. To achieve reforestation success, foresters must be able to characterize seedling performance potential with expected field site environmental conditions (Sutton 1988). Thus, a predictive stock quality assessment procedure needs to simulate expected field site conditions to determine what morphological parameters and physiological characteristics are important for successful seedling establishment.

[1]Paper presented at the Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia and Intermountain Forest Nursery Association meeting; 1988 August 8-11; Vernon, B.C. Canada

[2]S.C. Grossnickle is a research scientist at the Forest Biotechnology Centre, B.C. Research Corporation, Vancouver B.C., Canada; J.T. Arnott is a research scientist at the Pacific Forestry Centre, Canadian Forestry Service, Victoria B.C., Canada; J.E. Major is a research forester at the Forest Biotechnology Centre, B.C. Research Corporation, Vancouver, B.C., Canada.

Stock quality assessment over the last decade has evolved to include a wide array of both morphological and physiological measurement procedures (see reviews by Sutton 1979, Chavasse 1980, Jaramillo 1980, Schmidt-Vogt 1981, Glerum 1988). Ritchie (1984) organized these assessment procedures into two areas called material attributes (i.e. direct measurements: nutrition, morphology, water relations, bud dormancy) and performance attributes (i.e. whole seedling response: root growth capacity, frost hardiness, stress resistance) and they were the focus of a workshop held at Oregon State University in 1984 (Duryea 1985a). Duryea (1985b) indicated that stock quality assessment procedures have come along way. However, further refining of measurement procedures is required. Specifically, a stock quality assessment program should consider physiological processes critical to seedling field performance, seedlings must be assessed under environmental conditions defined as critical to limiting field growth and survival and there must be a battery of tests to assess morphological and physiological factors important in predicting field performance success.

Within this study, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western red cedar (*Thuya plicata* Donn)

seedlings, grown under four nursery cultural regimes, were examined for their capability to tolerate or avoid environmental conditions expected to influence establishment on a reforestation site. Based on stress tolerance/avoidance concepts of Levitt (1972), stock performance potential tests determined seedling's physiological and morphological response to optimal and suboptimal temperature and moisture conditions. Also measured were morphological parameters important in conferring desired stress avoidance characteristics. Only partial stock performance potential test results are presented in this paper, with further results to be reported in detail elsewhere. The actual effectiveness of a stock quality assessment procedure for predicting field survival and growth is part of an ongoing program funded by the Canada/British Columbia Forest Resource Development Agreement.

MATERIALS AND METHODS

Seedling Development

Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) seed (British Columbia Forest Service (BCFS Registered Seedlot no.3906; Lat. 48° 55" N, Long. 123° 55" W; elevation 340m) was stratified at 1° C for 4 weeks before sowing. Western red cedar (*Thuya plicata* Donn) seed (BCFS Registered Seedlot no. 7853; Lat.48° 50" N, Long. 124° 00" W; elevation 525m) was soaked in tap water for thirty-six hours prior to sowing. Both species were sown on March 2, 1987 in BC/CFS 313A styroblocks in a 3:1 mixture of peat and vermiculite with dolomite lime added to adjust the pH to 5.0 with coarse sand as a seed cover.

Seedlings were grown at the Pacific Forestry Centre, Victoria, B.C. (Lat. 48° 28" N). The greenhouse environment was maintained at a day/night temperature of 21/18° C, 50 percent relative humidity and natural light supplemented at night with high pressure sodium vapor lamps (i.e. 6µmol s^{-1} m^{-2}) to provide a sixteen hour photoperiod. Seedlings were watered and fertilized (i.e. 20-20-20 NPK with micronutrients) twice weekly (500 mg L^{-1}) and biweekly with the heptahydrate form of ferrous sulphate (155 mg L^{-1}).

Seedlings were grown under the above greenhouse regime until July 20, 1987 when mean seedling shoot height had reached 15.8 and 16.3 cm for western hemlock and western red cedar, respectively. At this point four dormancy development treatments were applied to one fourth of the seedling population for each species. The dormancy treatments were as follows:

1. Long-day wet (LDW); seedlings continued to receive the above greenhouse regime until the end of August.

2. Long-day dry (LDD); seedlings had the extended photoperiod as in the above stated greenhouse regime, but on July 20, 1987 the moisture stress treatment was initiated.

3. Short-day dry (SDD); seedlings, on July 20, 1987, had the moisture stress treatment initiated and had photoperiod reduced to eight hours on August 1,1987.

4. Short-day wet (SDW); seedlings continued to receive the above stated watering and fertilization regime until the end of August (as in 1) but had photoperiod reduced to eight hours on August 1, 1987.

All dormancy induction treatments were concluded on August 29, 1987, after which a regular watering and natural daylength regime was resumed. Fertilizer (10-51-16 NPK with micronutrients) was applied (500 mg L^{-1}) weekly until November and biweekly thereafter. Temperatures (day/night) were set at 20/10° C until 15 September, 17/8° C until 10 October, 15/5° C until 15 October, 13/4° C until 11 November, 10/3° C until 18 November and 8/0° C until seedlings were put into cold storage (2° C) on 11 January 1988.

In the moisture stress treatment, styroblocks were allowed to dry down to approximately 2.85 kg below their saturated weight before rewatering, plus fertilizing, to saturation and repeating the drying cycle. Throughout the six week period seedlings were subjected to six drying cycles. Seedling water status was monitored with predawn and noon xylem pressure potential readings during the moisture stress treatments. Xylem pressure potential readings were taken with a pressure chamber on six replicates from each treatment following procedures described by Ritchie and Hinckley (1975). Average predawn and noon xylem pressure readings for each species at the end of drying cycles were -0.3 and -0.7 MPa for western hemlock and -0.4 and -1.0 MPa for western red cedar, respectively. Though readings appeared to indicate little seedling water stress, many western hemlock

seedling shoots were wilted by the afternoon of the last day of each drying cycle. Thus,western hemlock shoot wilt was used as the indicator to end a drying cycle.

Statistical design of the greenhouse layout was a modified Latin Square. The four dormancy induction treatments were randomly assigned to four positions on the greenhouse benches. The two species were randomly assigned to opposite sides of each treatment block position. Over the course of the experiment styroblocks within a dormancy treatment were rotated every six weeks. Analysis at the end of the greenhouse operations showed no effect of bench location.

Seedling shoot height was nondestructively assessed (n=25) biweekly during the growing season, weekly during the dormancy treatment period and biweekly until October 23,1987.

Stock Performance Potential Tests

During January and February 1988 western hemlock and western red cedar seedlings in all treatments were assessed for physiological and morphological characteristics. Below is a brief description of the various stock performance potential tests.

Needle and root surface area

Surface area measurements were used to determine the needle transpiration area to root absorption area produced by all species/treatment combinations. Twenty-five seedlings from each species/treatment combination were dissected into workable shoot and root sections and processed through a Li-3100 (Li-Cor Inc.) area meter. Analysis of variance and Tukey's mean separation test were used to determine treatment differences within a species (Steele and Torrie 1980).

Root growth capacity

Standard soil/pot test.--Seedlings from each species/treatment combination were placed in pots (8 replicates with 3 seedlings per pot) containing a 3:1 mixture of peat and vermiculite plus dolimite lime (2Kg m^{-3}). Pots were placed in a completely randomized design within environmentally controlled (i.e. 22/10° C day/night temperature, 55% relative humidity, 16 hr photoperiod at 200 µmol s^{-1} m^{-2}) growth rooms. Seedlings were grown for seven days, after which root development was assessed using Burdett's (1979) semiquantitative scale.

Hydroponic test.--Root growth capacity was also assessed for all species/treatment combinations in a hydroponic system. Seedling root systems were placed in a darkened aerated aquarium at a water temperature of 5° or 22° C and then seedlings were grown in a controlled environment growth room (i.e. 22° C air temperature, relative humidity 50%, 16 hr photoperiod at 650 µmol s^{-1} m^{-2}) for fourteen days. Root development was assessed in all species/treatment combinations (n=10) after fourteen days. The root classification system used for RGC testing was modified from the classification scheme outlined by Burdett (1979). The root classification categories are as follows: 0 = no roots, 1 = new roots but none over .5 cm, 2 = 1 to 3 new roots over 1 cm, 3 = 4 to 10 new roots over 1 cm, 4 = 11 to 30 new roots over 1 cm, 5 = 31 to 50 new roots over 1 cm , 6 = 51 to 75 new roots over 1 cm, 7 = 76 to 100 new roots over 1 cm and, 8 = > 100 new roots over 1 cm. Analysis of variance and Tukey's mean separation test were used to determine treatment differences within a species.

Frost hardiness

Frost hardiness was assessed for all species/treatment combinations at -9,-12,-15 and -18° C test temperatures. Frost hardiness assessment was conducted by the B.C. Ministry of Forest and Lands, Surrey nursery. The method used was standard provincial procedure for the seedling browning test (Simpson B.C. M.o.F.L. personal communication). Seedlings from each species/treatment combination (n=40) were divided into two groups and assessed in a replicated experiment at the above mentioned temperatures. Analysis of variance and Tukey's mean separation test were used to determine treatment differences within a species.

Osmotic potential

Pressure-volume analysis was used to determine osmotic potential at saturation and turgor loss point for all species/treatment combinations. Six replicates for each species/treatment combination were used for determination of pressure-volume curves with techniques described by Hinckley et al. (1980). Osmotic potentials were then determined by using a software program (Schulte and Hinckley 1985). Analysis of variance and Tukey's mean separation

test were used to determine treatment differences within a species.

Needle resistance

Needle resistance was used to determine cuticular development for all species/treatment combinations. Seedlings were potted in a sand culture system, placed in the controlled environment room (described in the root growth capacity section), well watered for five days and then allowed to slowly dry down. Seedlings were assessed for needle resistance during the time they were well watered and after continuously monitored base xylem pressure potentials had reached -1.5 MPa.

Needle resistance was measured in a foliage cuvette with a porometer (Li-6250, Li-Cor Inc.). For each measurement period, readings were taken on ten randomly selected seedlings from each species/treatment combination. Readings were taken one to three hours after the lights went off in the evening. At the end of the experiment, sample branches were removed and needle surface area was determined with a Li-3100 area meter. Analysis of variance and Tukey's mean separation test were used to determine treatment differences within a species.

RESULTS

Growing season height growth

Western hemlock seedlings in the short-day treatments ceased shoot elongation by the end of the dormancy induction treatment, August 28, 1987 (Fig. 1). Seedlings in the long-day treatments continued shoot extension until early October. Short-day treatments had greater affect on the phenology of shoot growth than moisture stress treatments.

Western red cedar seedlings showed dormancy induction treatments to have no effect on shoot phenology or growth rate (Fig. 1). Short-day and moisture stress treatments did depress the rate of shoot growth, but not to any significant degree.

Needle and root surface area

Western hemlock seedlings in the LDW treatment had significantly more needle surface area than all other treatments (Fig. 2). Seedlings in the SDD and SDW treatments had the lowest and second lowest needle surface area, respectively. Root surface area was similar between all treatments.

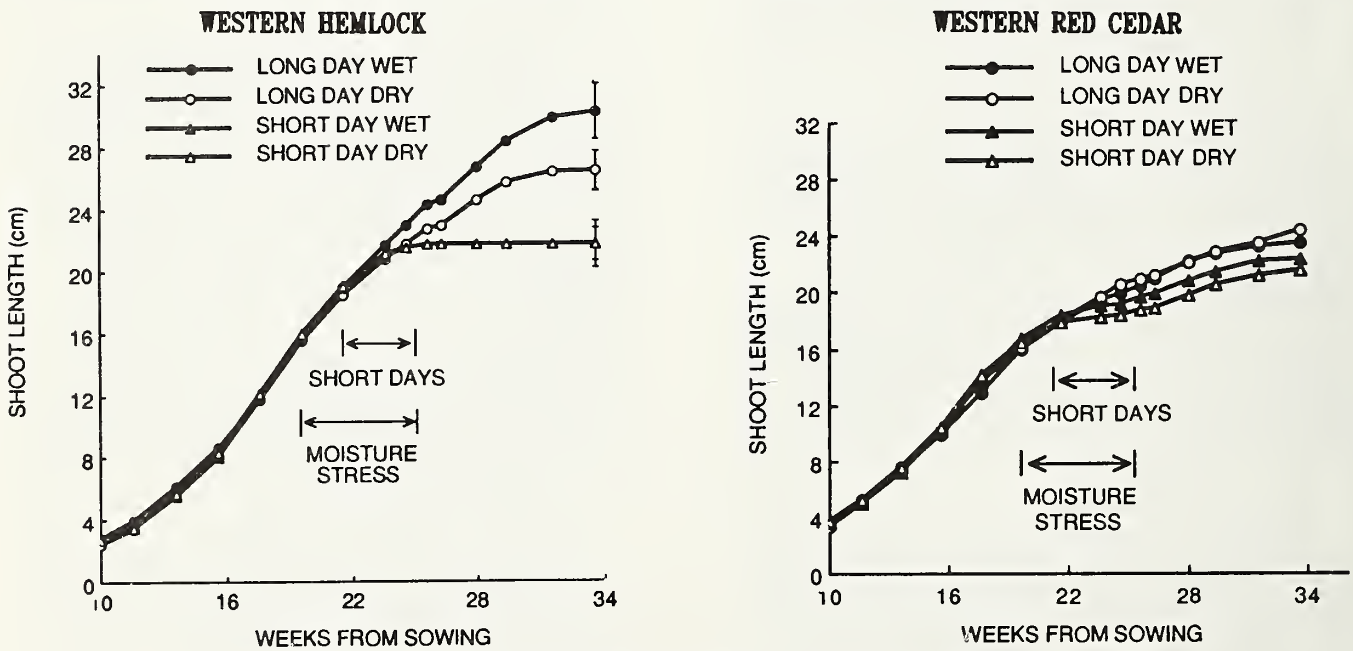

Figure 1.--Shoot length of western hemlock and western red cedar seedlings subjected to the dormancy induction treatments: a) long-day dry, b) long-day wet, c) short-day dry or d) short-day wet. Treatments (shown by arrows) were applied from July 20, 1987 until August 29, 1987. Vertical lines indicate ± 1 SE.

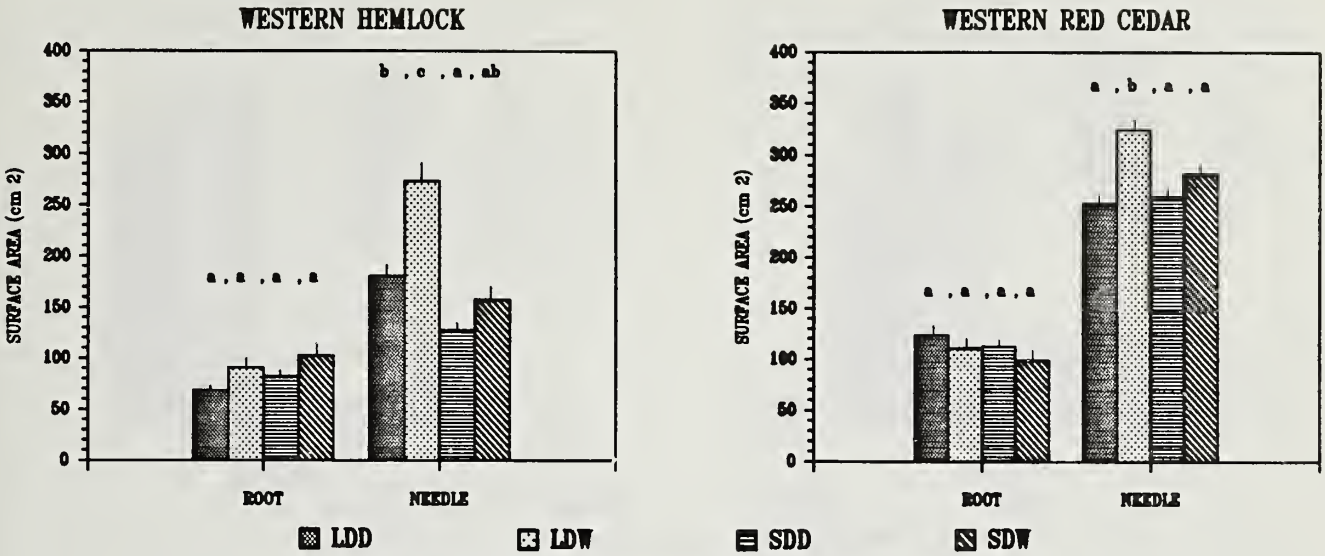

Figure 2.--Root and needle surface area (mean + SE) of western hemlock and western red cedar seedlings from the dormancy induction treatments: a) long-day dry (LDD), b) long-day wet (LDW), c) short-day dry (SDD) or d) short-day wet (SDW). Significant treatment differences, for roots or needles, determined by Tukey's mean separation test (p=.05) are shown by different letters.

Western red cedar seedlings in the LDW treatment had the highest needle surface area (Fig. 2). Root surface area was similar between all treatments.

Root growth capacity

Hydroponic root growth capacity (RGC) data for western hemlock at 22° C shows the SDD treatment produced more new roots than all other treatments while the SDW treatment produced the least number of roots compared to other treatments (Fig. 3A). In the soil/pot system LDD treatment had a significantly lower RGC (Fig. 3B). At 5° C new root growth was greater in the short day treatments compared to the long day treatments (Fig. 3A).

Western red cedar hydroponic RGC data at 22° C shows new root growth was greatest in the LDW treatment and least in the SDW treatment (Fig. 3A). There were no treatment differences for seedlings tested in the soil/pot system (Fig. 3B). At 5° C new root growth was low in all treatments (Fig. 3A).

Frost hardiness

Western hemlock seedlings in the LDW treatment had the greatest amount of needle damage at all measured temperatures (Fig. 4). Seedlings in the LDD treatment showed the second highest percent of needle damage at lower temperatures (i.e. -15 and -18° C). Seedlings in the SDW treatment had the least amount of needle damage at lower temperatures.

Western red cedar seedlings in the LDW treatment had the greatest amount of needle damage at all temperatures (Fig. 4). At lower temperatures (i.e. -15 and -18° C), seedlings in the SDW treatment had needle damage comparable to the LDW treatment. At -18° C seedlings in the LDD treatment had the least amount of needle damage.

Osmotic potential

Western hemlock seedlings in the SDW treatment had the most negative osmotic potential, at saturated and turgor loss point, of all treatments (Fig. 5). Seedlings in the SDD treatment had a more negative osmotic potential at turgor loss point compared to LDD and LDW, but not as negative as SDW. The LDD treatment showed the least negative saturated and turgor loss point osmotic potentials of all treatments.

Western red cedar seedlings showed no statistically significant difference between treatments at both saturated and turgor loss point (Fig. 5). However,

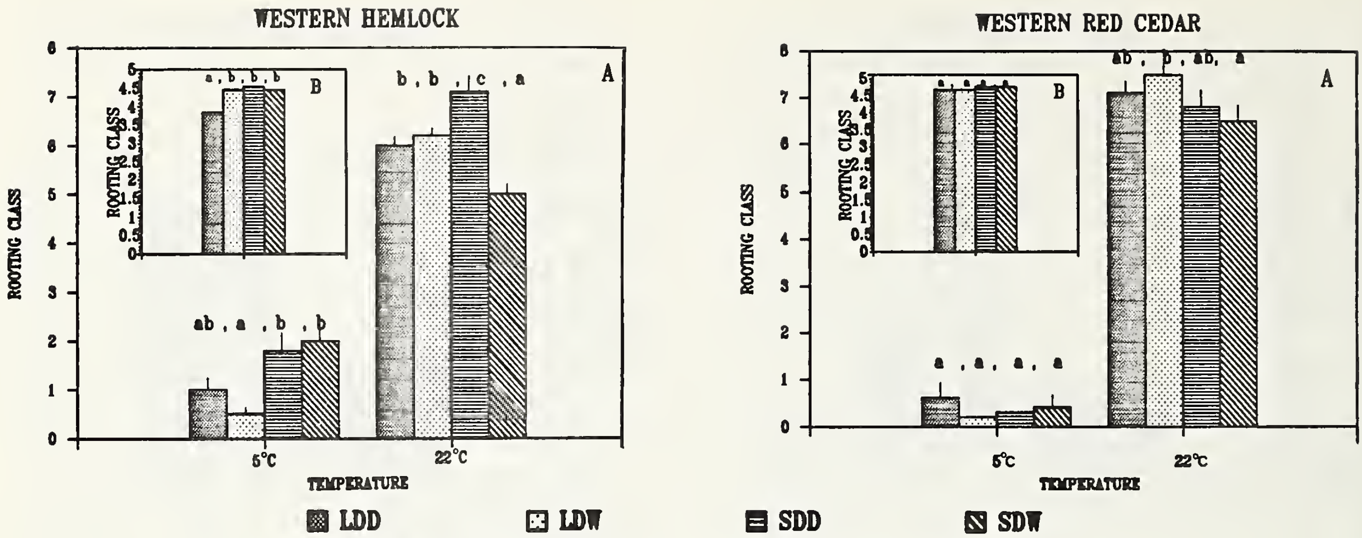

Figure 3.--Root growth capacity of western hemlock and western red cedar seedlings tested in hydroponic (A) or soil/pot (B) systems from the dormancy induction treatments: a) long-day dry (LDD), b) long-day wet (LDW), c) short-day dry (SDD) or d) short-day wet (SDW). Significant treatment differences, at a temperature, (mean + SE) in the hydroponic (A) system determined by Tukey's mean separation test (p=.05) are shown by different letters. Significant mean treatment differences in the soil/pot (B) system determined by Duncan's multiple range test (p=.01) are shown by different letters (SE of pop.+/-.16 for western hemlock and +/-.14 for western red cedar).

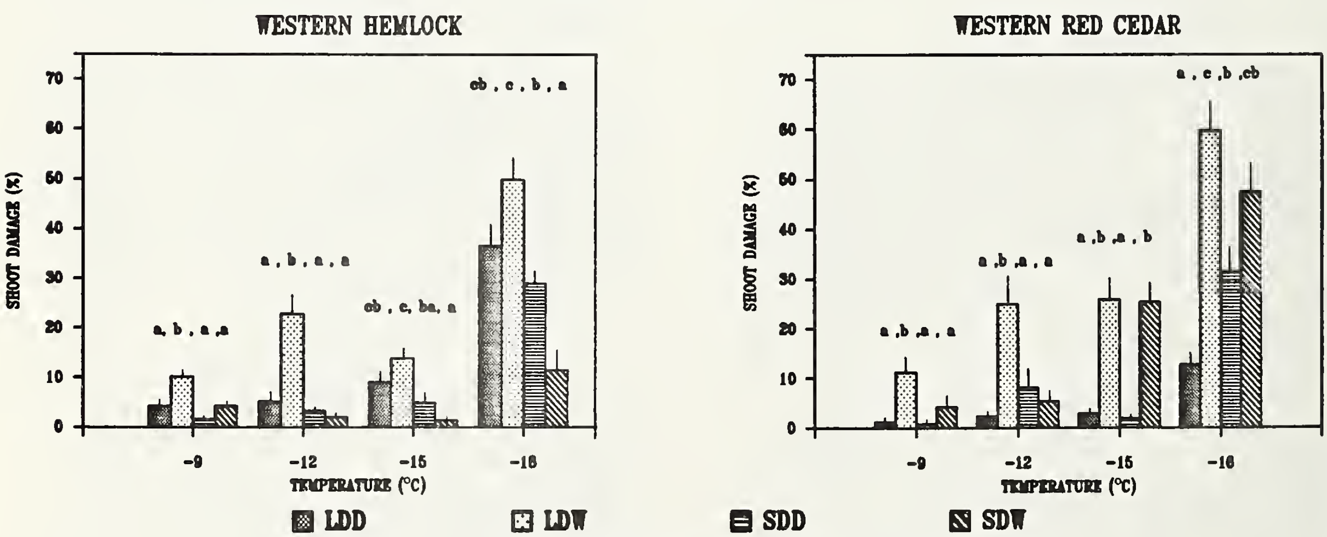

Figure 4.--Frost hardiness (mean + SE)of western hemlock and western red cedar seedlings from dormancy induction treatments: a) long-day dry (LDD), b) long-day wet (LDW), c) short-day dry (SDD) or d) short-day wet (SDW). Significant treatment differences, at a temperature, determined by Tukey's mean separation test (p=.05) are shown by different letters.

the moisture stress treatment did cause a slightly more negative turgor loss point osmotic potential.

Needle resistance

Needle resistance of well watered western hemlock seedlings showed no difference between treatments (Fig. 6). Under water stress conditions needle resistance was highest in the LDW and LDD treatments. Seedlings in the SDW treatment had the lowest needle resistance values, while SDD was slightly higher, under water stress conditions.

Western red cedar seedlings, under well watered conditions, showed no difference in needle resistance between treatments (Fig. 6). Under water stress conditions seedlings in the SDD treatment had the greatest level of needle resistance. Seedlings in the SDW treatment had the second highest level of needle resistance under water stress conditions, while seedlings in the LDD and LDW treatments had the lowest levels of needle resistance.

DISCUSSION

Western hemlock seedling development in the nursery showed short-days, applied in early August, stopped shoot elongation, while moisture stress did not. These results substantiate conclusions from a similar experiment conducted in 1986 and reported at this meeting (Arnott et.al. 1988). Western red cedar seedlings seasonal shoot height did not show any response to nursery cultural treatments. Apparently the cultural treatments were not severe enough or were not the proper environmental cues to change shoot height development.

A balanced root/shoot ratio, or more accurately the absorbing surface to transpiring surface ratio, is important in reducing the development of high seedling water deficits caused when absorption lags behind transpiration (Kramer and Kozlowski 1979). This reasoning was used for defining root and needle areas as one of the stock performance potential tests. Results showed short-day and moisture stress treatments reduced needle surface area in both species. Western hemlock seedlings in the LDD, SDW and SDD treatment had progressively less needle area, respectively, while all moisture stress and short-day treatment combinations in western red cedar reduced needle area equally. Other research has shown that short-days (review of literature Arnott and Mitchell 1982), moisture stress (Kramer 1969) or both (D'Aoust and Cameron 1982, Macey and Arnott 1986) can alter seedling shoot morphology.

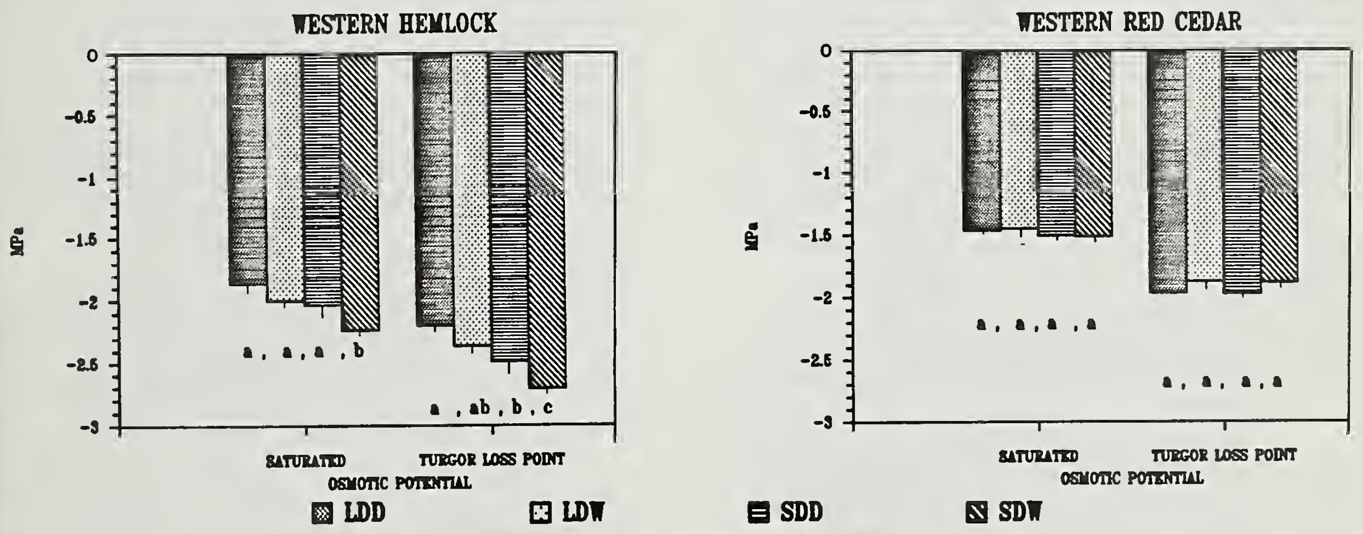

Figure 5.--Osmotic potential (mean + SE) of western hemlock and western red cedar seedlings from dormancy induction treatments: a) long-day dry (LDD), b) long-day wet (LDW), c) short-day dry (SDD) or d) short-day wet (SDW). Significant treatment differences, at saturated or turgor loss point, determined by Tukey's mean separation test (p=.05) are shown by different letters.

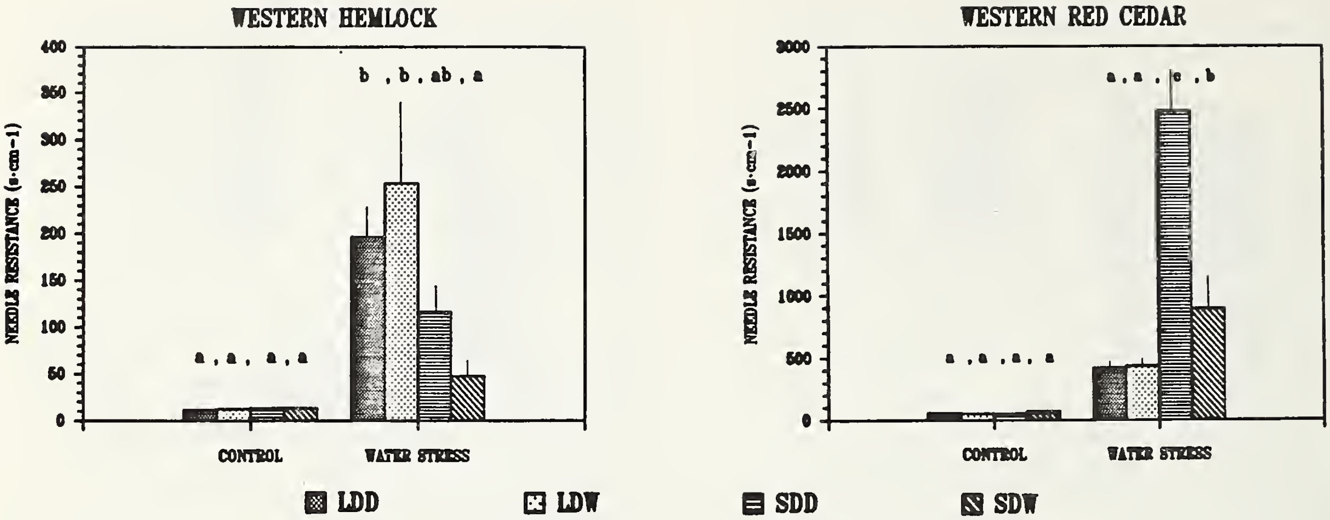

Figure 6.--Needle resistance (mean + SE) of western hemlock and western red cedar seedlings from dormancy induction treatments: a) long-day dry (LDD), b) long-day wet (LDW), c) short-day dry (SDD) or d) short-day wet (SDW). Significant treatment differences, within control or water stress, determined by Tukey's mean separation test (p=.05) are shown by different letters.

Root area in both species was similar in all nursery cultural treatments. This is contrary to the widely held belief that nursery cultural practices which stop shoot growth will result in a transfer of that seedling growth potential partially into root growth as well as into caliper and bud development (Ledig et al. 1970, Tinus and McDonald 1979). Upon examination of unreported morphological data, nursery cultural treatments did not alter caliper development in either species, but bud development in western hemlock was improved in the SDD and SDW treatments. Other researchers have also found that arresting shoot growth with nursery cultural practices did not result in reallocation of seedling growth potential into other areas of measurable seedling morphology (Heide 1974, Burdett and Yamamoto 1986, Arnott et al. 1988).

A quality seedling needs to have as high a root/shoot ratio as possible to ensure optimum field survival (Thompson 1985). Thus, short-day and moisture stress treatments in both species will improve the root/shoot ratio by reducing needle surface area development but not through enhanced root area development.

Results from root growth capacity (RGC) tests differed depending upon testing procedure. As expected, under optimal root temperature conditions the seven day soil/pot system produced fewer roots than the fourteen day hydroponic system in comparable species/treatment combinations. This difference between the two testing procedures was due to study length. Seedlings of both species tested at 22° C in the hydroponic or soil/pot system showed statistically significant treatment differences in RGC class. However, it is questionable whether this difference is biologically important because all RGC classifications were 5 or greater in the hydroponic system and 4 or greater in the soil/pot system. Outplanting studies comparing RGC with field survival have shown that above an RGC value of 1 to 3, field survival is usually greater than 80 percent (Burdett et al. 1983, Dunsworth 1986, Burdett 1987). Thus,seedlings from all species/treatment combinations produced in this study have the potential for good field survival.

However, it must be asked whether this testing method is a true representation of edaphic conditions a seedling encounters during early season planting. Seedlings are normally planted in late winter or early spring when soil temperatures are just above 5° C. An RGC test which examines root responses at low root temperatures might provide a stress tolerance test that more effectively predicts nursery cultural treatments influence on early root

growth in field planted seedlings. The low temperature test showed western hemlock seedlings in the SDW and SDD treatments produce RGC class values which have predicted good field survival in Pacific Northwest coastal conifers (Dunsworth 1986) compared to other treatments, while western red cedar seedlings did not show any treatment differences. Further work needs to be undertaken to determine whether a low temperature RGC testing procedure would provide useful information on seedling performance as it relates to field site conditions.

Frost hardiness testing was conducted on seedlings during the late winter to determine the level of frost tolerance provided by the nursery cultural treatments. Findings indicate that seedlings of both species in the LDW treatment had the least frost hardiness. Other researchers have also found that nonacclimatized seedlings will develop inadequate frost hardiness (Christersson 1978, D`Aoust and Cameron 1982, Colombo et al. 1982). Western hemlock seedlings developed greater frost hardiness in the short-day treatments, while western red cedar developed greater frost hardiness in the moisture stress treatments. Research has shown short-day treatments can improve frost hardiness (Timmis and Worall 1975, Christersson 1978, D`Aoust and Cameron 1982, Colombo et al. 1982), while moisture stress treatments can improve frost hardiness in some studies (i.e.Douglas-fir, Tanaka and Timmis 1974, Blake et al. 1979) but not in others (i.e. black spruce, D`Aoust and Cameron 1982). This difference in species frost hardiness response to cultural treatments needs to be considered when developing a nursery growing regime.

Interestingly, the combination of short-day and moisture stress was not as effective in conferring frost hardiness as just the short-day treatment in western hemlock and the moisture stress treatment in western red cedar. Work with black spruce has shown this same response (D`Aoust and Cameron 1982). This lack of synergism between short-day and moisture stress to improve frost hardiness indicates that the combined influence creates an environment too stressful for full frost hardiness development.

Osmotic adjustment in western hemlock seedlings was greatest in the SDW followed by the SDD treatment. Western hemlocks' osmotic adjustment in the short-day treatment is an interesting phenomenon. Dickson and Nelson (1982) working with cottonwood found short-day treatments used to induce dormancy increased the sugar levels in leaves. Sugars and organic acids have been shown to cause osmotic adjustment in a number of species (Osonubi and Davies 1978, Sharp and Davies 1979). Thus, the short-day treatment in western hemlock could have promoted increased sugar and organic acid production resulting in increased osmotic adjustment.

Western red cedar seedlings showed only a slight osmotic adjustment in the LDD and SDD treatments. Previously reported work with conifer seedlings has shown greater osmotic adjustment in response to moisture stress (Kandiko et al. 1980, Seiler and Johnson 1985, Bongarten and Teskey 1986, Grossnickle 1988). For western red cedar the problem seemed to be that the drying cycles were not long enough to develop sufficient seedling water stress for greater osmotic adjustment to occur. Further work needs to be conducted to develop moisture stress treatments that will provide maximum osmotic adjustment in western red cedar with minimum impact on other desirable seedling attributes.

Needle resistance is a combination of stomatal, mesophyll and cuticular resistances (Hinckley et al. 1978). As long as the stomata are partially open they are the primary factor influencing needle water loss. However, if the stomata are forced to close (e.g. via seedling water stress and/or darkness) the subsequent measurement of needle resistance would represent the cuticular resistance of the needles. This was the working hypothesis developed for the needle resistance stock performance potential test.

Western hemlock under water stress conditions (i.e. -1.5MPa) resulted in the LDW and LDD treatments having the greatest level of needle resistance. At first glance this would seem to be contrary to the working hypothesis. However, if needle resistance data is examined in conjunction with the osmotic potential data, it shows that needle resistance measurements were taken on seedlings that had never reached the turgor loss point (i.e. range from -2.2 to -2.7 MPa). Thus, these needle resistance measurements were taken at a medium level of water stress for western hemlock. In this condition the SDW and SDD treatments responded to the moderate water stress by keeping their stomata open slightly during the dark phase. Studies have shown that conifers

stomata, under low to moderate moisture stress, can remain open during the dark (Running 1976, Blake and Ferrell 1977).

Western red cedar seedlings showed high needle resistance in the SDD and SDW treatments at the -1.5 MPa measurement time. Western red cedar seedlings at this measurement time had daytime seedling water stress exceed their turgor loss point (i.e. range from -1.8 to -1.95 MPa) which resulted in stomatal closure in all treatments. Thus, when stomata were closed, the cuticular resistance was highest in the SDD and SDW treatments. Seedling water stress will produce seedlings with thicker more cutinized needles (Rook 1972), while short-day treatment in combination with low temperature have been found to reduce seedling transpiration rates (Christersson 1972). Short-day and moisture stress treatments seem to reduce needle water loss in western red cedar.

CONCLUSION

The intent of this stock quality assessment procedure was to develop a testing system that would characterize drought tolerance and avoidance plus frost hardiness and cold tolerance in western hemlock and western red cedar seedlings. This first approximation shows that there is merit to this approach because it provided a good overall picture of how seedlings, treated with different nursery cultural regimes, will respond to potentially deleterious field conditions. Further refinements of the needle resistance and low temperature RGC tests are required. Once refinements are incorporated, foresters will be able to determine seedling performance potential as it relates to both optimal and deleterious field site environmental conditions.

The findings reported show daylength and moisture stress nursery cultural treatments, as applied in this study, can influence the physiological and morphological characteristics of western hemlock, but only some morphological and physiological characteristics of western red cedar seedlings. Western hemlock seedlings in the SDW and SDD treatments and western red cedar seedlings in the LDD and SDD treatments had the best overall stock performance potential grade from the stock quality assessment procedure developed in this study. Further work is required to develop nursery cultural treatments that properly modify the seedlings physiological and morphological characteristics desired for improving establishment on reforestation sites.

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248 Using Frost Hardiness as an Indicator of Seedling Condition[1]

Jay R. Faulconer[2]

Abstract.--Knowing the frost hardiness of conifer seedlings is of benefit to nursery managers and seedling users even if the potential for actual frost damage is not of major concern. Examples are presented illustrating the ability of comparative hardiness testing to reveal variation in seedling phenology brought about by genetic, cultural, and environmental factors. Implications for the timing of cultural practices and lifting windows are discussed.

Introduction

The physiological condition of conifer seedlings during the lifting and planting season is of critical importance to the success of reforestation efforts. This subject has received much emphasis in recent years, reflected by ongoing efforts to estimate seedling quality using a variety of physiologically based tests, such as root growth potential (RGP), stress tests, dormancy release index (DRI), frost hardiness (FH), and others (Duryea, 1985). Although these tests are founded upon sound physiological theory, their success in accurately predicting stock performance in operational settings has been mixed. One reason for this is that quality tests can only assess potential stock performance. Even with high quality seedlings, poor handling or severe environmental stresses may still result in performance problems.

Another source of uncertainty has been the fact that seedling physiological condition may change between the time of testing and the time the seedlings are lifted or planted. Seedling condition, of course, changes continually throughout the year; this is reflected in the seasonal development of RGP, FH, and other seedling attributes. When a seedling lot is tested one time during the planting season, the results give a "snapshot" indication of the general condition of the seedlings on the date tested. This approach has proven to be satisfactory for the routine screening of large numbers of seedling lots, and for identifying lots with severe quality problems. However, because of the continual changes that seedlings undergo, a detailed understanding of seedling physiology can be obtained only through a "motion-picture" approach, that is, tracking seedling conditioning through tests conducted at intervals during the lifting/planting season. This can be done with several tests, either alone or in combination. Ritchie (1980) showed how RGP changes seasonally, rising from low levels in the fall to a midwinter peak, and then falling again in spring. Frost hardiness follows a similar pattern, and both appear to be related to the dormancy cycle. For the past several years, International Paper has used the physiological tracking approach for assessing proper lifting dates for seedling lots grown at its Kellogg Nursery. Each of the major tests has been utilized in this context; this paper will focus on the usefulness of frost hardiness testing as an

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indicator of seedling condition at various times throughout the planting season. The interplay of seedling genetics, nursery cultural practices, and environmental factors, specifically chilling hour accumulation, will be discussed with regard to their influence on hardiness development, and by implication, on proper lifting window.

Background

Reforestation is most successful when seedlings are handled at the time of maximum stress resistance. Stress resistance is an abstract term which is difficult to quantify. It includes such attributes as drought tolerance and frost hardiness, and is generally considered to be linked to the seedling dormancy cycle. While dormancy and stress resistance are difficult or time consuming attributes to quantify, it is relatively easy to measure frost hardiness. Although frost hardiness testing has received much attention in the past, interest has usually been limited to assessing the potential for frost damage to seedlings. As part of International Paper's seedling monitoring program, we have adopted as a working hypothesis that, as frost hardiness increases, overall resistance to stresses of all kinds also increases (Faulconer and Thompson, 1985). The basis for this assumption is the fact that frost hardiness develops as a result of metabolic changes such as cessation of active growth and physiological dehydration of various seedling tissues, indicative of a lowered state of metabolic activity for the entire seedling. Additionally, years of observations have indicated that maximum reforestation success is achieved in midwinter, when frost hardiness is at its peak, regardless of whether any frost damage has occurred. Tracking the seasonal development of frost hardiness thus becomes of interest even if the potential for actual frost damage to seedlings is not of major concern.

The rate at which seedlings enter dormancy and begin to develop resistance to stress is controlled by three categories of factors: the genetic background of the seedling lot, nursery cultural practices, and other environmental influences such as photoperiod and cool temperatures. If one or more of these factors differs between seedling lots, the timing and rate of their hardiness development may also differ, resulting ultimately in varying optimum lift dates for the seedlings. If the development of frost-hardiness is followed beginning early in the fall, divergent trends in hardiness development can be identified early enough to be used as a guide for lifting schedules and for assessing the storability of seedlings.

Methods

Frost hardiness testing is begun in the fall, as soon as hardening commences. Samples are lifted at biweekly intervals usually beginning on or about October 1. Each sample lot is divided into three or four subsamples, which are subjected to a gradient of increasingly severe simulated whole plant frosts in a programmable freezing chamber. Temperatures are chosen at which 20%, 50%, and 80% mortality is expected. After freezing, seedlings are placed in a greenhouse for five days to allow damage symptoms to develop. Damage to cambium, buds, and needles is then evaluated visually using the "browning" method. For each temperature run, percent mortality is estimated based on the severity of damage to the various tissues. Mortality is then plotted against temperature, and the LT-50, or lethal temperature for 50% of the seedling sample, is interpolated from the resulting line. The LT-50 is the term from which the hardiness development curves are derived. For a more detailed description of this and other methods of evaluating frost hardiness, see Burr et al (1986) and Schuch (1987).

As the season progresses, the frost hardiness development curve for each lot is plotted on a chart. This enables direct comparison of the hardening trends between seedling lots. Hypothetical example curves showing typical divergence of hardening trends are illustrated in figure 1. In this example, on any given sample date there is a spread of several degrees C in the LT-50s between these lots. If a target hardiness of, for example, -15 C is desired before lifting, then a comparison such as provided by figure 1 indicates a difference of several weeks for the opening of the lifting window between lots.

The remainder of this paper provides actual examples of divergent hardening trends and discussions of the causes of divergence. All examples are for coastal Douglas-fir grown at International Paper Kellogg Nursery. This data has been collected as part of our routine seedling monitoring program conducted each fall and winter. Frost hardiness monitoring ends as the seedlings are lifted and sent to the field; for that reason the following hardiness development curves end during midwinter.

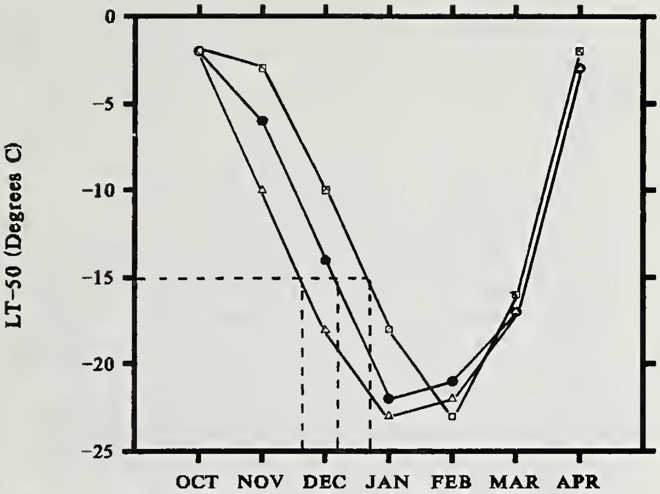

Figure 1. Typical divergence of frost hardiness development trends between three seedling lots.

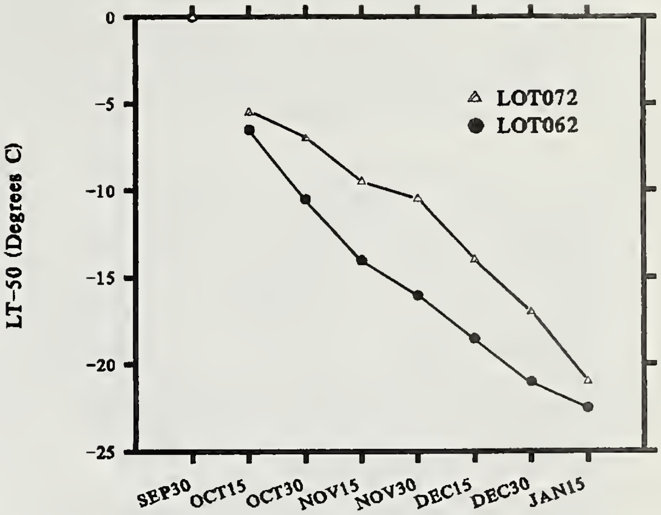

Figure 2. Comparison of frost hardiness development for two 2+0 lots from different seed sources (Oregon zones 072 and 062).

Genetic Variation

Jenkinson (1984) discussed at length the phenomenon of seed source lifting window. By plotting several years of plantation survival data versus lift date, for numerous seedling lots from the USFS Humboldt Nursery, he established that different seed sources have varying safe lifting windows. Because all seedlings were from the same nursery, receiving essentially the same cultural practices and exposed to the same climatic conditions, the factor responsible for lifting window variation was evidently seed source genetic variation. If the mechanism by which the genetic component influences lifting window is by determining the rate and timing of hardiness development during the fall, then variation in seed source lifting windows should be predictable by comparative frost hardiness testing of the various seed sources.

Figure 2 illustrates the frost hardiness development curves for two seedling lots at Kellogg Nursery in 1987-88. Both lots were 2+0s and were subjected to identical cultural practices and climatic conditions during both years in the nursery (in fact, the sample areas for the two lots were in adjacent beds). Seedlings from zone 072 0.5 (southern Oregon coast) lagged dramatically in hardiness development as compared to those from 062 1.0 (mid-Oregon coast). On any given sample date, the hardiness of the 072 lot, in terms of LT-50, was from 3 to 6 degrees C behind the 062 lot. In terms of lifting schedules, a more useful way to interpret this data is to say that the 072 seedlings were two to three weeks behind in hardiness development.

The tendency of seedling lots from the southern Oregon coast to lag behind more northerly or inland lots in hardiness development has been observed repeatedly for each year frost hardiness tests have been conducted. Jenkinson (1984) also found that the lifting windows for provenances from this general region consistently open later than for other sources evaluated. For two seed sources similar in origin to those illustrated in Figure 3 (072 Powers and 061 Alsea), he discovered a spread in the opening of the lifting window nearly identical to the spread between the frost hardiness development curves of the corresponding Kellogg lots. This suggests that fall hardiness development trends and seed source lifting windows are directly related. If so, then frost hardiness testing would offer nursery managers a substantial shortcut for establishing lifting windows for various seed sources.

Nursery Cultural Practices

Nursery cultural practices can have a great impact on the induction of dormancy in seedlings, and on the subsequent development of hardiness. Practices such as the withholding of nitrogen or induction of moisture stress are designed to cause the

cessation of active growth in preparation for the fall and winter. These practices interact with, and to an extent sometimes override, the genetic component controlling dormancy development, potentially resulting in an additional source of variability in hardening trends between seedling lots.

The most important phenological effect of cultural manipulation of nursery seedlings is probably the timing of final budset, which in nurseries can occur anytime from midsummer to autumn. Frost hardiness tests indicate that hardiness development can be strongly affected by the timing of budset. Figure 3 illustrates the FH development curves for two seedlots from Kellogg Nursery. In this example, the two lots were sown with the same seedlot (zone 252 1.0) in the spring of 1986. Lot 1 was sown for 2+0 seedlings, whereas lot 2 was lifted after the first year and transplanted for 1+1 production. The genetic background of the lots was identical, as was nursery environment and climate. The divergent hardening trends between the lots must therefore be due to the variation in cultural regimes for the two stock-types. The 1+1 lot reached target height early in the second year, and the seedlings were "shut down" by mid-July through moisture stress treatments. For the 2+0 lot, in contrast, height control was achieved partially through top-mowing, which though effective, can delay final bud set. As a result, the timing of budset differed significantly for the two lots.

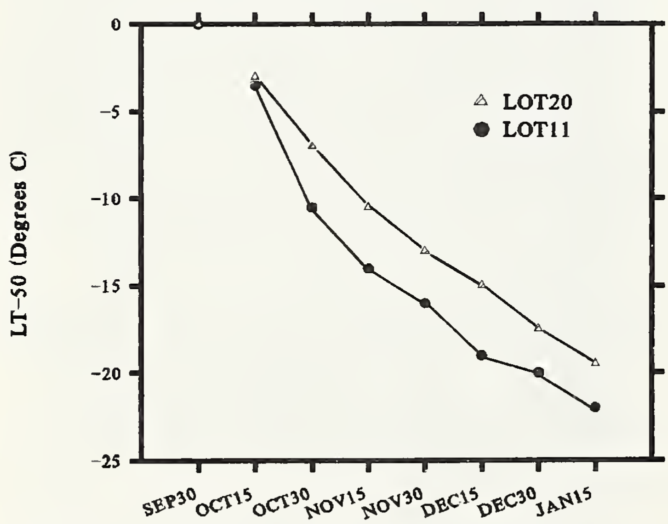

Figure 3. Comparison of frost hardiness development trends for 2+0 and 1+1 seedlings sown with the same seedlot (Oregon zone 252 1.0).

Lavender and Stafford (1984) demonstrated the importance of early budset in order for seedlings to properly respond to the cool temperatures which condition seedlings in the fall and early winter. They showed that a period of mild, short days occurring after budset was necessary for subsequent cool weather to be fully effective in satisfying chilling requirement. The frost hardiness curves for these two lots indicates that early budset will also hasten the subsequent development of hardiness. This suggests that cold hardiness and fulfillment of chilling requirement are physiologically linked, which was hypothesized by Ritchie (1986). It would appear then that the timing of the lifting window is determined by the efficiency with which seedlings respond to fall and winter chilling, which can be measured by rate and degree of frost hardiness attainment.

Environmental Conditions

Besides genetics and nursery cultural practices, the third major variable affecting seedling hardiness development is the nursery climate, especially exposure to cool temperatures. As discussed above, genetics and cultural practices interact to produce seedlings that are either more or less predisposed to efficiently respond to chilling. From then on, the amount of chilling actually received is the most important determinant of hardiness development.

Nursery climate varies geographically between nurseries, and annually within a single nursery. One commonly used method to deal with this variability is to quantify the duration of cool temperatures experienced by seedlings. Hours during which the temperature is less than a specified minimum are defined as chilling hours, and the accumulated number of such hours experienced by seedlings is used as a guide for predicting seedling condition.

Although use of chilling hour accumulation is easy, inexpensive, and provides an instantaneous assessment of seedling condition (one can always know the number of hours accumulated on any given day), sole reliance on chilling has several disadvantages. First, as discussed earlier, seedling lots which have been exposed to the same amount of chilling may be in very different stages of hardiness development. Secondly, there is apparent disagreement regarding the effective temperature range of a chilling hour. Jenkinson (1984) defines it as being less than 10 C, whereas Ritchie (1986) uses temperatures below 6 C.

Other researchers have used only temperatures <u>between</u> 0 and 5 C in the belief that very cold temperatures retard the physiological processes driven by chilling. Finally, there is uncertainty as to the effect of interruptions of chilling accumulation by unseasonably warm temperatures.

The type of uncertainty which can result from sole reliance on chilling hours as a guide is illustrated in figures 4 and 5. Figure 4 represents graphically the accumulation of chilling hours (defined here as hours cooler than 6 C) at Kellogg Nursery for two consecutive years, 1985-86 and 1986-87. Due to mild weather in the fall of the second year, chilling accumulation lagged far behind that of the first year. The oft-cited 300 hour minimum requirement before safe lifting may commence was not reached until mid-January, about six weeks later than the previous year. Figure 5 compares frost hardiness development for the two years for zone 252 2+0 Douglas-fir. Although development in 1986-87 did lag behind that of the previous year, the delay was not nearly so dramatic as might have been expected from the chilling hour data. One possible explanation is that cultural practices differed somewhat between the two years and offset the difference in chilling. More likely is that in 1986, temperatures slightly outside the arbitrary range, which did not count toward the cumulative total, were still effective in stimulating hardiness development and in satisfying chilling requirement.

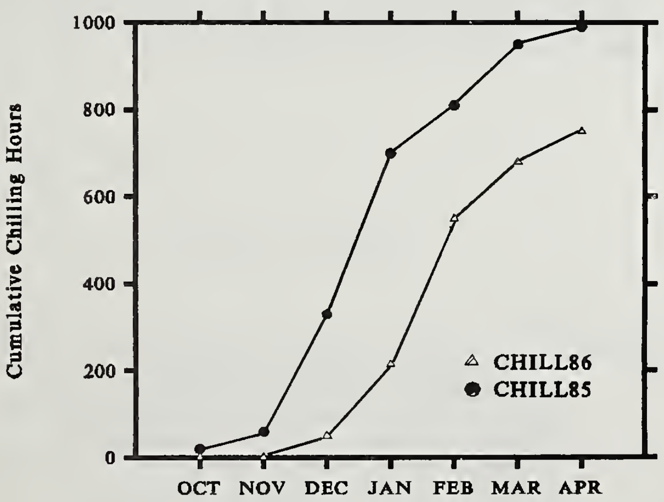

Figure 4. Chilling hour accumulation at Kellogg Nursery for 1985-86 and 1986-87.

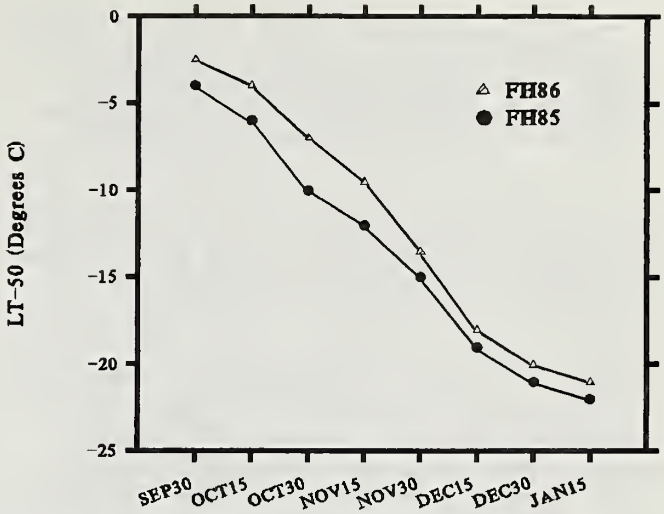

Figure 5. Comparison of frost hardiness development trends for zone 252 1.0 2+0 seedlings in 1986-86 and 1986-87.

Because of the variability between the large numbers of seedling lots produced at most nurseries, and because chilling hours are apparently poorly defined, reliance on chilling hour accumulation alone as an indicator of seedling condition will likely result in an overly generalized and potentially inaccurate assessment of the status of nursery seedlings. Different species and seed sources may have different chilling requirements in terms of number of needed hours, and they may be responsive to different temperature ranges. Attempting to establish guidelines which would account for the multitude of seed sources, and for the variability introduced by cultural practices, would be a monumental task. Much easier is to simply measure the seedlings' integrated response to the genetic, cultural, and climatic factors responsible for their hardiness development.

Frost Hardiness and Storage

The preceding sections have illustrated how frost hardiness testing can detect differing rates of hardiness development between seedling lots. At this point it is still uncertain what hardiness level should be attained before lifting, storage, and planting may proceed safely. However, some preliminary work measuring the effects of cold storage on frost hardiness has provided some clues. Figure 6 illustrates a portion of a typical hardiness development curve for Douglas-fir 2+0 seedlings tested during the fall and early winter of 1987. On each lift date, one sample was tested immediately; another

was placed in cold storage to be retested on the next lift date. The objective was to determine whether hardiness continued to develop in storage, and to compare the hardiness of stored seedlings with those which remained in the nursery. For the first lift dates, when seedlings were still in the early stages of hardiness development, an apparent loss of hardiness occurred during storage. Later, as the hardiness of seedlings in the nursery beds deepened, it appears that an ability to maintain hardiness in storage developed. Viewing frost hardiness as an indicator of overall seedling physiological status, this suggests that the physiological stability of seedlings in storage increases as hardiness deepens. In this example, it appears that lifting and storage before attainment of an LT-50 of approximately -15 C will result in a loss of seedling vigor.

Other observations have indicated that storage of seedlings lifted after significant dehardening has begun also results in further loss of hardiness (Ritchie 1986). It is generally recognized that the quality of seedlings lifted either too early or too late will decline in storage. By measuring the amount of hardiness lost in storage, it should be possible to quantify "too early" and "too late" in terms of LT-50 on the lift date.

In contrast to these results, Burr (1989) found that interior Douglas-fir continued to harden or even reversed dehardening when placed in cold storage, regardless of the hardiness level at the time storage commenced. However, this work was conducted with containerized seedlings which remained upright and undisturbed in

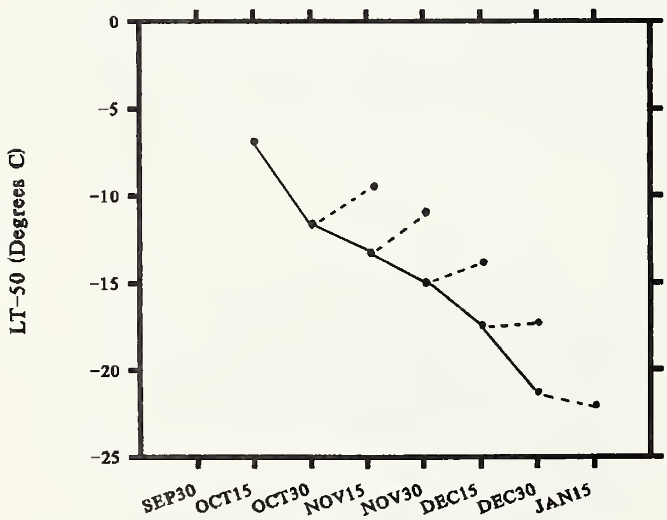

Figure 6. Effect of cold storage on frost hardiness development of coastal Douglas fir. Dotted lines connect LT50 points from fresh samples with stored samples from the same lift date.

the containers during the storage treatments. The storage treatments discussed in the previous paragraph involve bare-root seedlings which have been lifted from the beds and stored horizontally in tightly packed paper bags, similar to operational storage practices at a bare root nursery. The contrast in effect on frost hardiness development between the two differing storage treatments suggests that the shock associated with bare root lifting and storage prevents or retards further physiological changes during storage which would result in continued hardiness development. The fact that undisturbed seedlings which are placed in storage are capable of further physiological development serves to emphasize the importance of minimizing the stresses associated with bare root lifting, and to conduct the lifting when resistance to stress is at its peak.

Conclusion

The foregoing observations regarding the value of frost hardiness testing as an indicator of seedling condition have resulted from several years of International Paper's operational seedling monitoring program. More formal research is needed to confirm the hypotheses presented in this paper and to further investigate the relationship of frost hardiness to other physiological attributes of nursery seedlings. Specifically, the correlation between frost hardiness and overall stress resistance should be more firmly established, and more information is needed regarding the effects of storage on frost hardiness. In the meantime, however, there is little doubt that comparative frost hardiness testing can reveal significant differences between the phenological cycles of different seedling lots, with important implications for the timing of cultural practices and lifting operations.

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Monitoring Viability of Overwintering Container Stock in the Prairies — An Overview of a Five Year Lodgepole Pine Study[1]

Ian J. Dymock[2]

Abstract. Overwintering viability of first year containerized lodgepole pine seedlings was monitored using a series of morphological assessments, dormancy tests and freezing tolerance(cold hardiness) tests. Results presented outline the phenology of dormancy and cold hardiness development. The impact of environmental factors is discussed in relation to the overwintering success.

INTRODUCTION

This presentation will provide some insight into the study results obtained from our research on monitoring viability of overwintering container stock. We have been working with five species of conifer seedlings that are grown for reforestation purposes on the Canadian prairies. At this time, I will restrict my talk to our lodgepole pine data.

In a production nursery situation, where containerized stock is to be overwintered outdoors, nursery personnel can rely on the shortening natural photoperiod, during the latter part of the summer, to initiate the onset of dormancy in their seedlings. The gradual reduction in the day and night temperatures triggers the gradual development of cold hardiness.

While the induction of dormancy and cold hardiness is achieved under ambient conditions, it often must be achieved in a relatively short period. This is particularly true for nurseries in cold temperate regions, where early frosts can be a serious problem.

It is therefore imperative, for the nursery personnel to have a good understanding of the basic physiology involved in successful overwintering of container seedlings. It is also important for staff to have rapid and reliable tests at their disposal in order to monitor the development of dormancy and cold hardiness in their seedlings.

Our study on overwintering physiology had three purposes then, in light of the preceding discussion:

1. To evaluate methods for the determination or testing of seedling dormancy and cold hardiness.

2. To investigate the relationships between terminal buds, the stem(cambium) and roots, and the phenology of dormancy and cold hardiness development during overwintering.

3. To provide a better understanding of the basic physiology of overwintering in conifer seedlings that could aid in the development of improved nursery management practices.

The results presented will provide you with an overview of five year's efforts in this study.

MATERIALS AND METHODS

Rearing and sampling schedules

Seedlings of lodgepole pine(*Pinus contorta* var. *latifolia* Engelm.) were reared in Spencer-Lemaire Fives according to the methods of Carlson(1983), using schedule 2 for hardiness zone 3.

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Details of the rearing and sampling schedules can be found in Dymock and Dendwick(1987, 1988).

Morphological assessments

The morphological assessments made at the initial time of sampling included the following: height and root collar diameter measurements; visible damage assessment of seedling shoots, needles, buds and roots; shoot and root fresh(FW) and oven dry weights(DW); calculation of seedling shoot/root ratios(S/R) based on fresh and dry weights; and the calculation of shoot and root moisture content.

Dormancy tests

Dormancy tests were conducted on stems(cambium) using the oscilloscope-/square wave deformation(SWD) technique of Ferguson, Ryker and Ballard(1975), but using the coding system of Dymock and Dendwick(1987).

Root dormancy was monitored using the root growth capacity(RGC) method of Burdett(1979) and the scoring system for estimating the numbers of new roots over one cm in length.

Shoot(bud) dormancy was monitored by determining the time to bud break (TTBB) using conditions similar to those used in the RGC test. Seedlings remained in the greenhouse until all buds had broken and seedlings were fully flushed. The average number of days to complete bud break(TTBB) were then calculated.

Freezing tolerance tests

Initial tests were carried out during 1983-84 using rapid freeze/thaw cycles. Whole seedlings in containers were placed in cold rooms or freezers set at -5C, -10C and -15C for 6, 24, or 168 hr. Control seedlings were left at 20C. At the designated times, seedlings were rapidly brought to room temperature, subjected to oscilloscope/SWD testing and then moved to the greenhouse.

Four weeks later, shoots and roots were assessed for visible damage. Shoot and root assessments were added to yield a seedling survival rating. Seedlings rated -5 or higher, were considered survivors, while those rated below -5 had little chance of survival.

The rating system used to assess visible damage to shoots and roots, was modified from the one previously reported by Dymock and Dendwick(1987). It has been modified to more accurately reflect degrees of damage, and is as follows:

Rating	Symptoms of pine shoot damage
0	No visible damage to the shoot terminal, stem or needles.
-1	Terminal bud alive; no apparent stem damage; < 20% dead needles.
-2	Terminal bud alive; no apparent stem damage; 20-50% dead needles.
-3	Terminal bud alive but shows some damage; 50-90% dead needles.
-4	Terminal bud dead; most of upper stem and lateral branches dead; < 10% live needles, most of them emerging from lower stem area.
-5	Shoot completely dead; no living tissue present.

Rating	Symptoms of pine root damage
0	More than 10 new roots > 10 cm long; many white root tips.
-1	4-10 new roots > 10 cm long.
-2	1-3 new roots > 10 cm long.
-3	Some new roots, but none > 10 cm long; some white root tips.
-4	No new roots or white root tips; some loss of turgor in old roots.
-5	No live roots; roots dark brown to black in colour; no turgor; bacterial/fungal growth evident.

Supplemental freezing tolerance tests were carried out during the 1984-85, 1985-86 and 1986-87 seasons. Whole seedlings in containers were subjected to -5C, -10C and -15C for 24 hr periods only. Controls were maintained at +5C.

After 24 hr, seedlings were rapidly thawed and brought to room temperature. Conductivity testing of shoots and roots was done using the method of Colombo, Webb and Glerum(1984) but with those modifications reported by Dymock and Dendwick(1987). Seedlings were also potted and returned to greenhouse conditions for visible damage assessments four weeks later.

From the conductivity test results, the mean percent relative conductivities of shoots and roots were calculated. The index of injury for each set of shoots and roots from each freezing temperature was then calculated according to Colombo et. al.(1984).

Environmental parameters

Weather records were collected over each overwintering period. These include the period from the time seedlings were moved outdoors to the shadeframes, until the following spring.

Shoot temperatures(at bud height), root plug temperatures, and air temperatures at 1.8 metres, were routinely

monitored using a Campbell Scientific CR-7 Micrologger equipped with copper-constantan thermocouples.

Long term records, and corroborating daily records from the closest local weather stations, were obtained, from the Canadian Climate Control Centre of Environment Canada(Downsview, Ont.).

RESULTS

Morphological assessments

Seedling height and root collar diameter measurements from all five study seasons are shown in figure 1. In all cases, height growth was completed prior to late August. Root collar diame-

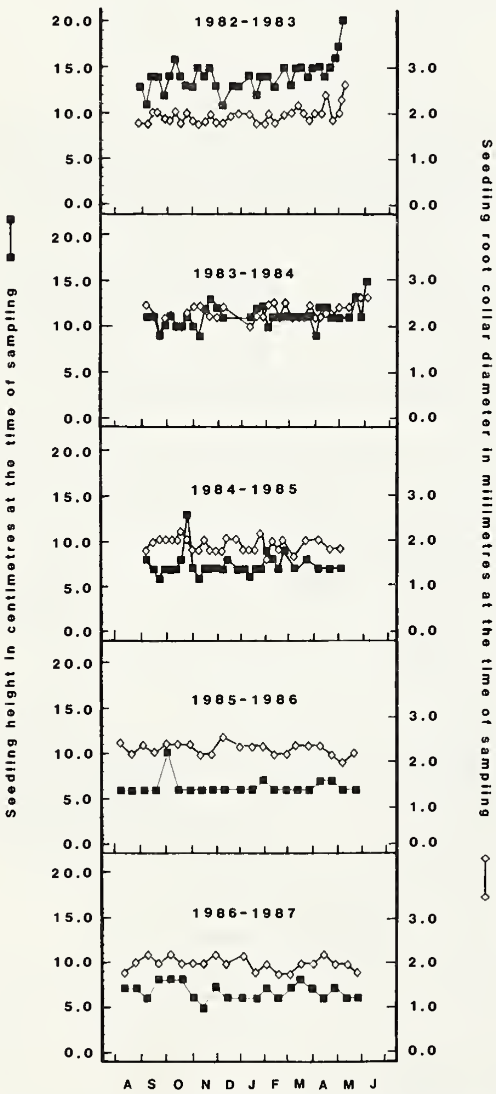

Figure 1. Comparative seasonal changes in height and root collar diameter over five overwintering periods.

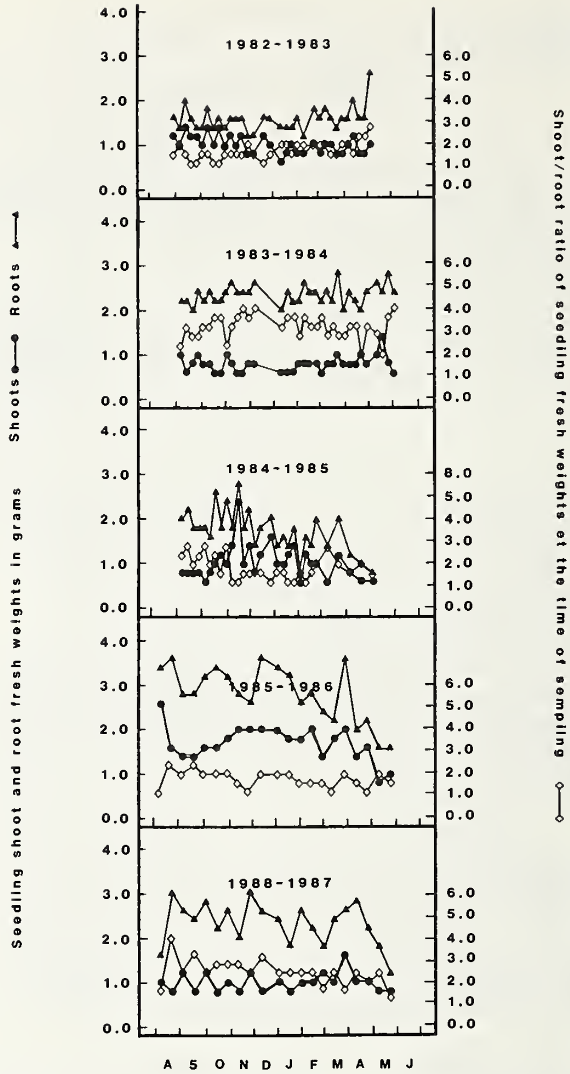

Figure 2. Comparative seasonal changes in shoot and root fresh weights and shoot/root ratio of fresh weights over five overwintering periods.

ter continued to increase for some time yet into September. No appreciable changes in either parameter would be expected again until spring, as seedlings begin to flush.

Height began to increase again in the springs of 1983 and 1984 but not in each of the following three years(fig. 1). Similar results are seen for root collar diameter measurements(fig. 1).

Parallel results can be seen in figure 2 for the shoot and root fresh weights and the S/R(FW) ratios. In the latter three seasons, pronounced drops in mean shoot fresh weights are quite evident.These began at different times, but always closely following the early

loss of snow cover from the seedlings (data not shown).

There was no comparable decline in either the shoot(or root) dry weights (data not shown). However, the shoot FW loss that is seen in figure 2, is clearly seen in figure 3 as a loss in shoot water. This was observed in each of the 1984-85, 1985-86 and 1986-87 seasons. The rapid loss of shoot water content closely paralleled the loss of snow cover from the shoots(data not shown).

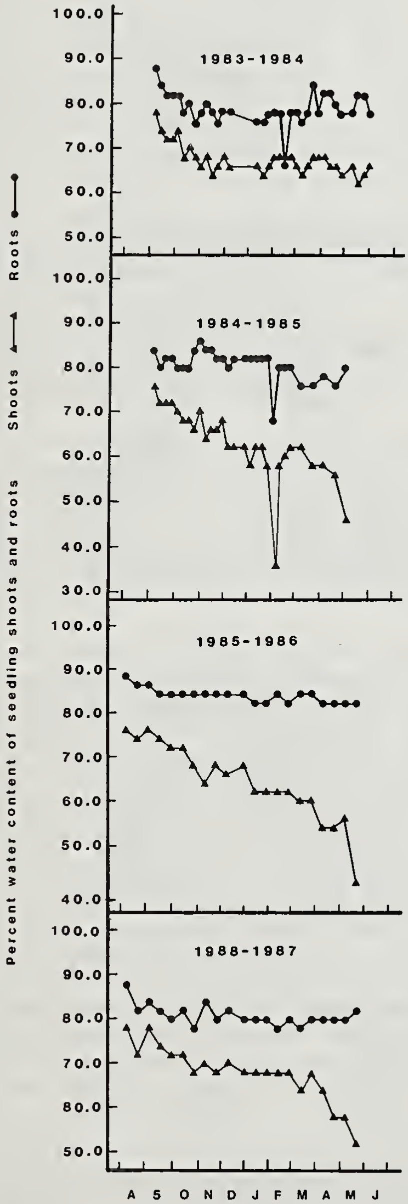

Figure 3. Comparative seasonal changes in shoot and root moisture content over four overwintering periods.

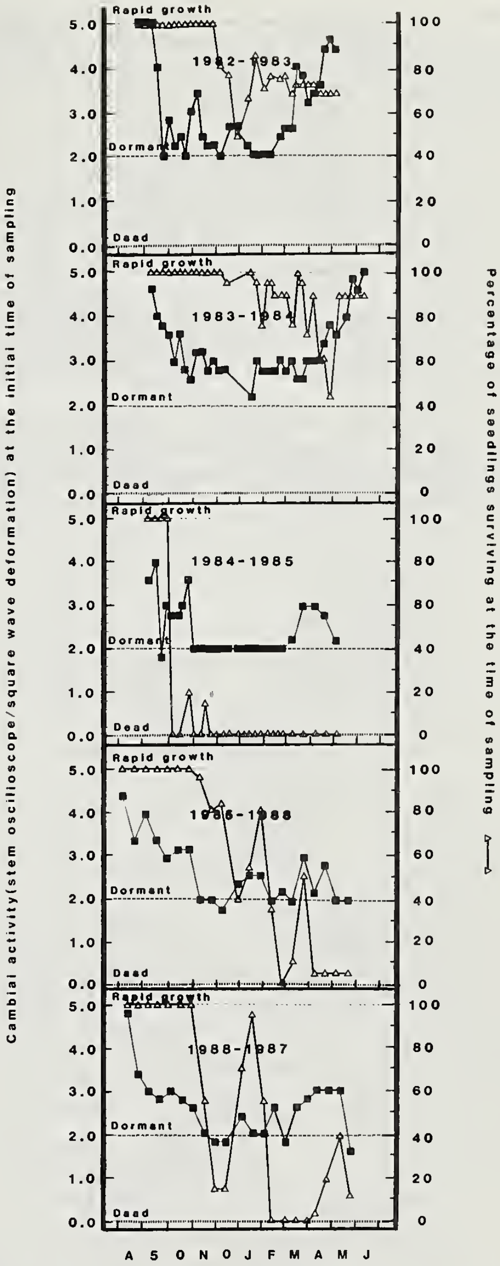

Figure 4. Comparative stem activity and percent seedling survival over five overwintering periods.

Dormancy tests

Stem(cambial) activity declined during the fall of the year, although this was quite variable(fig. 4). Stem activity was quite variable during the winter months. Only during the 1984-85 season did stem activity appear to remain dormant for a prolonged period.

Seedling survival throughout the sampling periods, was highly variable,

as seen in figure 4. It generally showed a mid-winter decline during most of the study seasons, and began to increase again towards the spring in some but not all seasons.

Root dormancy, as monitored by the RGC test, dropped with time during the early fall months, but this was quite variable(fig. 5). During 1983-84, there was a slow increase in RGC as seedlings came out of dormancy in the late spring. However, during each of the three succeeding seasons, little sustained root activity was observed after mid-winter.

Shoot(bud) dormancy, as monitored using the TTBB test, showed a much more regular annual pattern as seen in figure 5. The TTBB was very high initially in

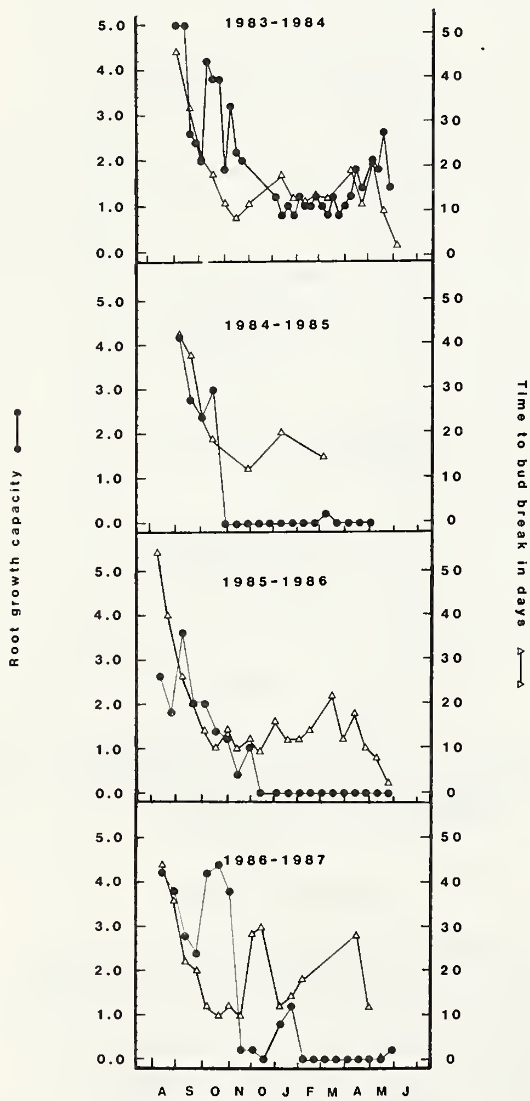

Figure 5. Comparative root growth capacity and time to bud break over four overwintering periods.

each season and declined to an early minimum by November of each year. Secondary increases in TTBB occurred later during most winters before dropping off prior to the spring flush.

Freezing tolerance tests

Results of initial freezing tests during 1983-84, are shown in figure 7. The seasonal trends in stem activity, and freezing tolerance of seedling shoots and roots are seen quite clearly.

Rigorous nonparametric statistical testing was conducted on the results. Temperature comparisons within the duration classes were conducted for each parameter(ie. oscilloscope/SWD trace; shoot damage; root damage). Results showed that as the freezing temperature decreased, the damage increased, giving the ordering as: Controls<-5C<-10C<-15C for all classes(data not shown).

Similar analyses of duration comparisons within the temperature classes were conducted. Initial tests indicated that there was an ordering effect for duration with respect to shoot damage for each temperature(6hr<24hr<168hr), but only for roots at -5C. Duration had no significant effect on stem activity.

Further analysis indicated that duration had a significant effect on shoot damage between 6 and 168 hr at -5C and -10C, but had only a marginal effect at -15C. There was only a significant duration effect on root damage at -5C (data not shown).

During the 1984-85, 1985-86 and 1986-87 seasons, supplemental freezing tolerance tests were conducted for 24 hr only. The results are shown in figure 7. It can be seen that seedlings in these three years were unable to reach the same levels of hardiness that were reached by seedlings from the same seedlot, during the 1983-84 season(fig. 6).

Results from conductivity testing of shoots and roots indicated that roots were slower to harden than shoots. It was also shown that the roots did not achieve the same levels of hardiness to the lower test temperatures(data not shown). This was also seen, but to a lesser extent, in figure 7 with respect to shoot and root visible damage.

Environmental parameters

Figure 8 shows the weather records for each of the overwintering seasons in this study. In the first portion of this

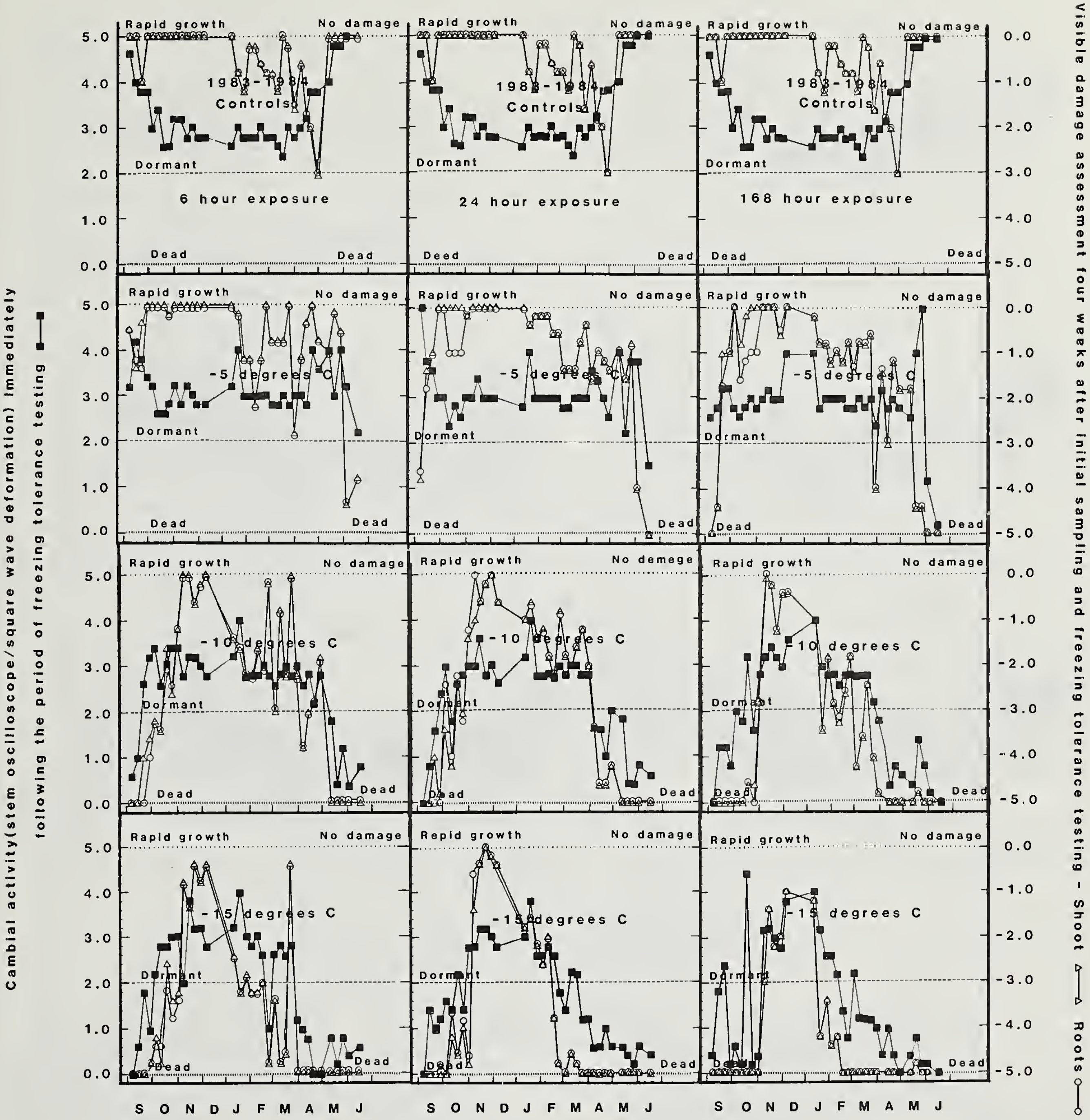

Figure 6. Influence of freezing temperatures and duration of exposure on stem(cambial) activity and visible damage to shoots and roots during the 1983-84 overwintering period.

figure(fig. 8a), are plotted the values for the mean daily minimum and maximum temperatures for the 30 year period from 1941-1970. Also shown are the daily extreme minimum and extreme maximum temperatures from 100 year records to 1981.

The mean annual period from first to last frost, growing-degree days, and hardening-degree days, derived from the 1941-70 period, are also shown(fig 8a). The daily range in temperatures, from minimum to maximum, are indicated by the

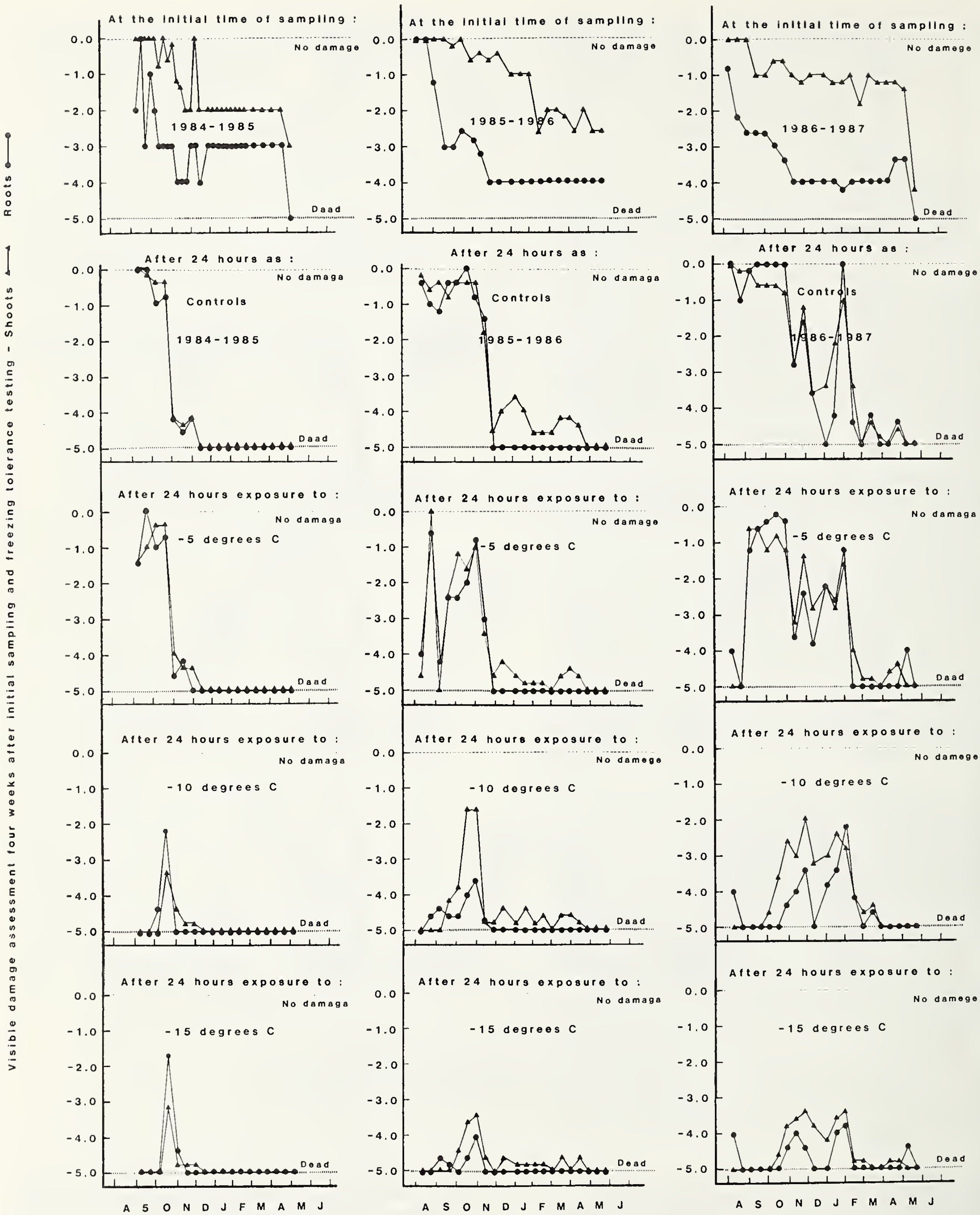

Figure 7. Comparative influence of freezing temperatures on visible damage to shoots and roots over the 1984-85, 1985-86 and 1986-87 overwintering seasons.

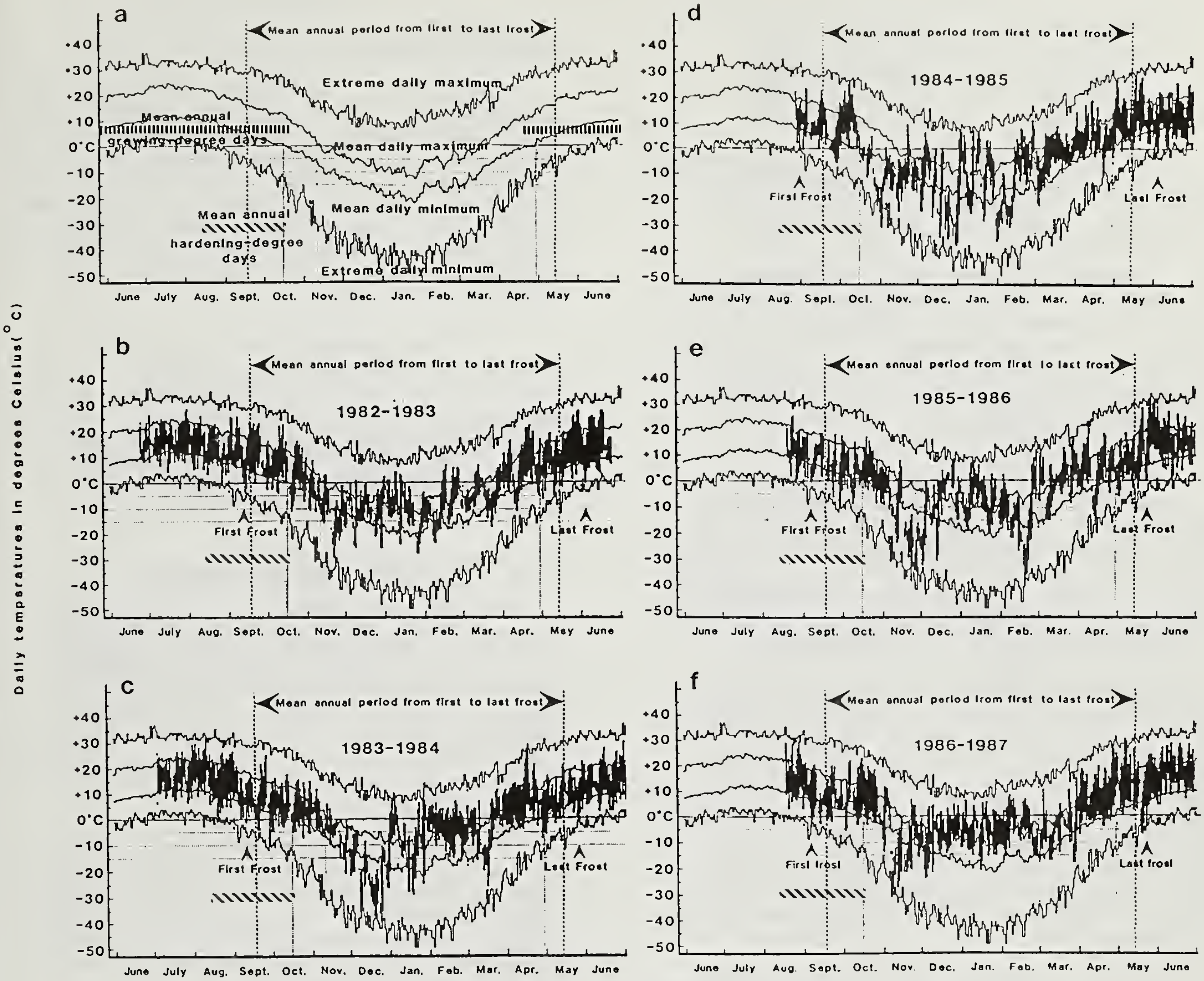

Figure 8. Mean daily temperature data for the 1941-70 period for Edmonton, Alberta and the daily records for each overwintering season.

vertical black bars that overlay the means(fig. 8b-8f). They begin on the day that seedlings were moved outdoors, and continue through to the end of the sampling season the following spring.

These records, and the impact of the environmental parameters are the primary focal point for the remainder of this presentation.

DISCUSSION

The principle feature that can be discerned from the weather records in figure 8, is that the 1982-83, 1983-84 and 1986-87 seasons were closest to normal (ie. the 30 year means) during the critical hardening period.

This period can be considered to occur from the time that the seedlings are moved outdoors, to the middle of November(fig. 8). At this point, for 1983-84, seedling shoots and roots were approaching their most hardy state, relative to -15C(fig. 6)

There are 295.8 cumulative hardening-degree days that can be expected between August 14 and October 18. The cumulative hardening-degree days for each season, and the percentage deviations from the expected mean were:

1982-83	336.5(+13.8%)
1983-84	270.5(- 8.6%)
1984-85	172.5(-41.7%)
1985-86	191.5(-35.3%)
1986-87	281.3(- 4.9%)

During the first year of freezing tolerance testing(1983-84), the number of hardening-degree days just fell short of the expected mean(-8.6%).

For each of the next two seasons in 1984-85 and 1985-86, seedlings were subjected to temperature variations that were frequent and unusually severe. They often occurred during the early hardening stages(figs. 8d and 8e). Warming cycles also presented problems as will be discussed shortly.

For 1984-85, the large drop in the hardening-degree days was likely due to the numbers and severity of early frost events that occurred during late August and throughout September(fig. 8d). They were followed by very severe conditions and early snows in mid-October that persisted well into the winter months.

These conditions greatly decreased the potential number of hardening-degree days for the seedlings. They were more than sufficient to arrest any further development of cold hardiness, as has been shown in figure 7. There was also a significant impact on stem activity and seedling survival(fig.4), and on bud and root dormancy(fig. 5). The end result, was a crop that had insufficient time to properly achieve full dormancy and cold hardiness.

Similar extremes were experienced in the 1985-86 crop. The conditions that occurred during the critical hardening period significantly retarded the full development of a satisfactory overwintering state.

This was further exacerbated by unusually mild conditions during the second half of the winter(fig. 8e). This in turn contributed to the shoot damage that became apparent(figs. 2 and 3) with the loss of snow cover. Survival then dropped rapidly(fig. 4), due to the loss of water from the shoots.

In both years, there was little capacity for any new root growth(fig.5). This was partially due to the failure of roots to sufficiently harden during the fall, due to the numbers and severity of early frosts. Shoots of those seedlings brought indoors for testing, continued to flush, at least initially. They did perish, however, due to their inability to generate new roots, caused by the earlier freezing damage(fig. 5).

In 1986-87, hardiness developed along normal lines(fig. 7), but did not reach the levels observed in 1983-84 (fig. 6). This crop started to decline in survival during late January 1987. This was at the time when very warm temperatures developed, and snow cover was lost. These conditions were prevalent throughout the rest of the winter and into the spring.

The now exposed shoots suffered from rapid water loss and winter drying, with the advent of above freezing temperatures(fig. 8f). The still frozen roots were unable to replace the water lost from the shoots(fig. 3), due to increased metabolic activity, and seedling mortality increased(fig. 4).

SUMMARY AND CONCLUSIONS

In the latter three seasons, the failure of each overwintering crop was due to two factors. Initially, these were due to the early and severe frosts. These were then coupled with warming temperatures during the latter part of the winter, which precipitated increased seedling mortality due to winter drying of exposed shoots.

Each test utilized in this study was useful in monitoring the progress of the seedlings as dormancy and cold hardiness developed. Each provided a good evaluation of seedling status, for the parameter under investigation, at each of the sampling dates.

When this point information was combined over a season and compared to the environmental data, then reasons for the success or failure of the crop became apparent. This type of testing and analysis, then, is of paramount importance for nurseries that overwinter container crops outdoors.

Point sampling lets staff monitor viability of the stock and should allow for precautionary protective measures to be taken, in advance, when adverse weather conditions are expected. Similar sampling and testing immediately following exposure to severe conditions, also allows for a fairly rapid diagnosis of damage that may have been incurred.

These tests and the information derived from them, then, would provide nursery management with an additional tool to aid in decisions on the ultimate fate of the stock.

ACKNOWLEDGEMENTS

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Root Growth Potential as an Indicator of Outplanting Performance: Problems and Perspectives[1]

Thomas D. Landis and Susan G. Skakel[2]

Abstract.--Root growth potential (RGP) tests have not always proven to be good predictors of outplanting performance under operational conditions. Problems include sample collection, handling, and storage; testing environment; root growth rating system; species differences; outplanting site conditions; and development of an accurate and precise prediction equation. Unless better prediction equations can be developed or threshold points defined, RGP tests should be used primarily as a test of seedling vitality, not relative vigor.

INTRODUCTION

Seedling quality is one of the most widely discussed topics in nursery and reforestation science these days. The 1984 Evaluating Seedling Quality workshop focused new attention on the subject, and the workshop proceedings are considered a primary reference (Duryea 1985). Following this workshop, many nursery managers and reforestation specialists became inspired and either built their own seedling testing equipment or initiated a regular program of seedling quality analysis by independent testing facilities.

Of all the various seedling quality tests, root growth potential (RGP; also called root growth capacity - RGC) is probably the most widely-used, and can be defined as a measure of the ability of a seedling to produce new roots when growing in an ideal environment (Ritchie 1985). The RGP concept is intuitively attractive - more new roots means better survival and growth (Sutton 1980). RGP tests are currently being used by many reforestation foresters as a way to predict the outplanting performance (either initial survival or subsequent growth) of a group of nursery seedlings.

After several years of trying to analyze and apply the results of RGP tests, however, a certain backlash has developed. Many foresters are finding that there is considerable variability in their test results, and that they are not always good predictors of field survival and growth. Binder and others (1988) present results of large-scale operational trials that attempted to predict outplanting performance with RGP tests, and discuss the limitations of this practice. One of the problems is that many nursery managers and foresters tend to oversimplify some of the basic concepts inherent to RGP tests. Actually, the problem may not be the tests themselves, but how they are applied. The situation is analogous to using a pipe wrench to tune-up the carburetor on your car - there is nothing wrong with the tool itself, only the way that you are trying to use it.

USING RGP TESTS TO PREDICT OUTPLANTING PERFORMANCE

RGP tests from research laboratories have generally been found to correlate relatively well with seedling outplanting performance, either survival or growth after outplanting. Burdett (1987) provides a listing of the principal studies.

One way to introduce the relationship between RGP tests and outplanting performance is to examine an array of RGP test results, and outplanting performance over a variety of real-life situations. The following table presents different combinations of RGP test results taken at two different times: a pre-shipping test at the nursery and a

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[1]Paper presented at the combined meeting of the Western Forest Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association. Vernon, B.C., August 8-11, 1988.

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pre-planting test in the field. These test results can be arrayed against various outplanting performance scenarios:

	RGP Test Results		Outplanting
	Pre-shipping	Pre-planting	Survival
1.	GOOD	GOOD	POOR
2.	POOR	GOOD	GOOD
3.	POOR	POOR	GOOD

In situation 1, nursery stock was in good condition at the nursery, it was shipped, handled and stored properly, and planting quality was good. However, site conditions were not conducive to good survival. Even under the best seedling quality and handling procedures, seedlings may not survive under extreme site conditions.

The stock in situation 2 was in poor condition at the nursery. Handling and site conditions were ideal, however, resulting in good survival in spite of poor stock quality. It is also possible that the nursery test was in error; sampling procedures, shipping timeliness and quality, or errors in testing are problems that can confound RGP test results.

Situation 3 has posed a dilemma for many foresters. The reason for poor RGP test results, but good field performance is simple, however. Outplanting performance is a function of two factors: seedling quality and outplanting site conditions (Sutton 1987). Seedlings of poor quality will perform much better on a good site, with ideal outplanting and seasonal growing conditions, than they will under stressful site conditions. Under ideal site conditions, even seedlings with low RGP will survive and grow well.

PRACTICAL SIGNIFICANCE OF RGP TESTS

On an operational level, RGP tests can have two different interpretations:

1. Qualitative. RGP tests are a good indicator of seedling vitality - seedlings that are able to produce a reasonable amount of new roots are obviously alive (Burdett 1987). The RGP test is actually a modification of the traditional "pot test", in which seedlings were planted in containers and placed in a favorable environment to see if they were alive (Binder and others, 1988). As such, RGP tests provide a simple "YES-NO" answer about the viability of the sample seedlings at the time of the test.

2. Quantitative. The second interpretation of an RGP test is that the amount of new roots is somehow related to outplanting performance. To make this interpretation, the new root production must be quantified according to some relative root growth scale, and then a mathematical relationship established with outplanting performance (Sutton 1987). As mentioned earlier, the assumption that more new root growth means better performance than less new new root growth is a seemingly reasonable hypothesis. In the following section, we will discuss some of the problems with this assumption.

REASONS THAT RGP TESTS MAY NOT CORRELATE WELL WITH OUTPLANTING PERFORMANCE

1. Sampling considerations. The number of seedlings used in an RGP test is really quite small and may not be representative of the population at large. A sample of 60 seedlings, which is the number usually required by seedling testing laboratories, is only 0.12% of a moderately-sized seedlot of 50,000 seedlings.

The sample must also be randomly collected from throughout the seedling population. It is relatively easy to collect a random sample when the seedlings are still in the seedbed or on the grading table, but sampling becomes more difficult once the stock has been packaged and stored. It is operationally difficult to sample from bagged seedlings, because a number of bags must be accessed, opened, and the sample collected from throughout the bag, not just from the top layer of seedlings. Sampling during frozen storage would be almost impossible.

RGP test results are only representative of the larger population at time the sample was taken. As soon as the samples are collected, they are under a different set of environmental conditions than the original seedling population, and many things can happen to the original seedlot from the time of lifting until they are outplanted. The RGP rating of a seedlot should remain relatively stable in cold storage, although it has been shown to vary (Sutton 1980), most likely in seedlots that were not completely dormant at the time of lifting.

The timing of RGP tests deserves special mention. RGP test scores will vary with the physiological status of the seedling, particularly in response to its environment. If you are interested in outplanting performance, therefore, the best time to sample the seedlot is as close to the time of planting as is operationally possible. Tests performed on seedlings at the time of lifting will probably not accurately reflect the condition of the seedling at time of planting, although they are useful to evaluate nursery cultural practices.

RGP tests are not instantaneous, either. Most RGP tests take several weeks for handling, shipping and processing so it may take as long as 4 to 6 weeks to receive test results.

2. Poor handling after sample collection. Again, once the samples are collected they are being subjected to different conditions than the original seedling population. Poor handling

practices, poor packaging for shipping to the testing facility, delays during shipping to the testing facility, or a prolonged storage period at the testing facility can seriously affect the test results. Seedlings submitted for RGP tests should be kept cool, packaged in insulated containers, and shipped to insure that they will arrive at the testing facility within 48 hours. In one operational RGP testing program, poor sampling or storage were implicated as the reason for confusing tests results on one sampling date (Zensen unpublished manuscript).

3. Failure to maintain "ideal" environmental conditions during the RGP test. Because it measures potential root growth, RGP tests should be run under greenhouse-like conditions. Burdett (1979) recommends a standard ambient environment of:

Day temperature	30^{o} C (86 ^{o}F)
Night temperature	25^{o} C (79 ^{o}F)
Relative humidity	75%
Daylength	16 hr.
Light intensity	15,000 lux

This standard environment is for the atmosphere surrounding the seedling shoot, however, not necessarily the root. Root environments can vary considerably between the three different RGP testing environments: potted seedlings, hydroponic (aerated water), and aeroponic (mist chamber). Because of the low cost of materials and ease of operation, the hydroponic ("fish tank") RGP test is used by many reforestation foresters conducting their own tests at field locations (Palmer and Holen 1986). Although results from the 3 different test environments have been correlated under laboratory conditions, there may be operational problems in maintaining a proper test environment at remote field sites. Temperature and aeration of the water in the tank are extremely important, as is excluding light from the roots. Root aeration may be especially important with species that are particularly sensitive to flooding injury.

4. The problem of quantifying new root growth. Unfortunately, the root system is the most difficult part of a seedling to observe and measure. Because roots are so fragile and can grow rapidly, measuring new root growth during RGP testing is even more of a problem. Sutton (1987) discusses the difficulty of quantifying RGP and some of the various measurement systems that have been used.

Many people are using Burdett's root rating scale for quantifying the amount of new root growth in RGP tests (Burdett 1979). Because this rating system offers a considerable savings of time and effort in evaluating new root growth and was also one of the first to be published, it has been widely accepted as the standard:

Root Growth Rating	Number of New Roots
0	None
1	Some, none > 1 cm long
2	1 to 3 > 1 cm
3	4 to 10 > 1 cm
4	11 to 30 > 1 cm
5	31 to 100 > 1 cm
6	101 to 300 > 1 cm
7	300 + > 1 cm

Use of this one scale to rate new root growth has obvious advantages:

* It is much easier and faster to count new roots than to measure them.

* Speed of root growth may be more indicative of seedling vigor than total amount of new roots, so this 7-day rating system may be better than other 28-day tests.

but it also has some serious limitations:

* This root rating system was not developed using any morphological or physiological data relating the amount of roots that are necessary for a seedling to successfully become established and grow.

* Different seedling species produce new roots at different rates. The 7-day rating system apparently worked well under laboratory conditions for coastal Douglas-fir [*Pseudotsuga menziesii* (Mirb.)Franco] and a number of other northwestern conifers (Burdett 1987), but some species, such as true firs (*Abies* spp.), do not even initiate root growth for at least a week under these environmental conditions.

5. Failure to recognize physiological differences between species. As mentioned in the previous section, different species have different root production patterns. Compared to Douglas-fir seedlings, ponderosa pine (*Pinus ponderosa* Dougl. ex Loud.) produce fewer, larger diameter roots, which would result in a lower RGP rating using Burdett's scale. Tinus and others (1986) studied RGP patterns for ponderosa pine, Douglas-fir and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) over 4 different environmental stages and found considerable species variation, particularly with ponderosa pine. Using a standard root evaluation scale for all species may lead to faulty conclusions about seedling quality - it may

be necessary to define specific standards for different species or groups of species.

The standard RGP test environment was designed around the optimum growing regime for commercially important tree species, such as coastal Douglas-fir. Different species, and even different ecotypes, grow different lengths and volumes of roots, over different time periods, and at different soil temperatures (Sutton 1980). For example, some true firs, such as noble fir (Abies procera Rehd.), cease root growth at approximately 18 °C (65° F), even though common RGP test procedures use root mist chamber or water bath temperatures of 18 to 21 °C (65 to 70 °F). Based on these currently-used test environments, RGP results would be erroneously low for noble fir.

6. Overriding effect of outplanting site conditions. The environment on the outplanting site, particularly soil moisture, is crucial to seedling performance. Under extremely moist conditions, most seedlings will survive irrespective of their RGP ratings whereas under xeric conditions, few seedlings may survive. This "filtering effect" of environment is probably one of the most confounding factors in attempting to correlate seedling quality indices with outplanting survival. Burdett (1987) discusses this conundrum and emphasizes that RGP tests do not predict actual seedling survival, but only survival potential.

7. Defining the relationship between RGP and outplanting performance. One of the assumptions in using RGP tests to predict outplanting performance is that there is an identifiable mathematical relationship between the amount of roots that a seedling can produce under ideal conditions and how well that seedling performs after outplanting. Through the use of regression analysis, a prediction equation can be developed and used to estimate outplanting performance (the dependent variable), using RGP values (the independent variable).

This relationship is probably not a simple linear regression, however, and may involve more complicated statistical manipulations. The addition of other independent variables (multiple regression analysis) may help the precision of the prediction equation; perhaps inclusion of a variable to describe relative outplanting site conditions would be useful. Few relationships in nature can be predicted with one variable and it is naive to assume that outplanting performance is any different.

A more realistic possibility is that there may be a "threshold point" at which the mathematical relationship between RGP and outplanting survival changes form or becomes useless due to excessive variation. This threshold point hypothesis is both logical and useful. Regression analysis assumes that there is a continuous mathematical relationship between the amount of new roots that a seedling can produce and outplanting performance - few roots means poor suvival and growth and more roots means better performance. Actually, under given outplanting site conditions, there is probably some critical number or amount of roots necessary for initial survival: seedlings with fewer roots do not survive whereas seedlings with more roots not only survive but grow in proportion to the number of new roots. Dunsworth (1986) proposes a threshold RGP value of 1.0, using Burdett's scale, as "red light/green light" for determining whether a group of seedlings should be outplanted. An RGC threshold value (10 roots greater than 10 mm in length per seedling) has been proposed as a batch culling guideline for several northwest conifer species (Simpson and others 1988).

CONCLUSIONS AND RECOMMENDATIONS

1. Keep RGP and other seedling quality tests in perspective. There is no single answer for predicting seedling outplanting performance. Because of the complexity and interrelationships involved, we don't currently have, and probably never will have, a single test for measuring seedling quality. To continue with the tool analogy introduced earlier, it takes more than one type of tool to tune-up your car. Other quick, one-test measures of seedling quality, such as the "dormancy meter" (Jaramillo, 1981), have not proven to be operationally useful.

2. RGP is only one aspect of seedling quality, and should be considered in concert with other seedling quality information. Cold hardiness tests, because they are indicative of overall seedling stress resistance, may be more useful for predicting outplanting performance, especially if they include an associated test of seedling vitality. Dunsworth (1986) suggests that measures of stress resistance, such as cold hardiness and dormancy, may be good predictors of seedling survival. Ritchie (1985) proposes that RGP tests are actually reflecting stress resistance, which is more related to outplanting performance than "the ability to grow root per se".

3. The timing of seedling quality tests, including RGP, is important. For reforestation purposes, the best time to monitor seedling quality, including RGP, is as close to the outplanting period as possible because seedling quality can change significantly due to storage and handling. The next best sampling time would be just prior to shipment from the nursery. Seedling quality tests taken during seedling harvesting should be used to evaluate nursery performance rather than outplanting success.

4. It is traditional to conclude these technical papers with the observation that "more research is needed". One productive area of research would be to develop better root growth rating systems that can be adjusted for different species of seedlings. Future research may also clarify the relationship between RGP and

outplanting performance. Perhaps there is some magic formula that will mathematically describe this relationship and allow precise and accurate predictions, although it is doubtful. More likely, future research will reveal a "threshold" RGC rating, which varies with species, that will help to differentiate between good seedlots and ones that are critically weak.

5. This discussion should not be interpreted to infer that RGP tests are useless for predicting outplanting performance. On the contrary, RGP tests do provide some valuable information but, until we can better define the relationships involved, they should be interpreted primarily as a measure of seedling vitality, not relative vigor.

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Author's Note: This paper is the result of informal discussions with many different people, and much of this information is unpublished. Therefore, while we cannot cite their individual contributions, we would like to acknowledge them: W. Lopushinsky, D. Henneman, and D. Simpson.

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245

Root Growth Potential: Facts, Myths, Value?[1]

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Abstract.-- Currently the Root Growth Potential (RGP) test enjoys a reputation as a general predictor of outplanting survival and growth. This study examines the accuracy, precision and repeatability of RGP. We conclude that the present use of RGP is neither highly accurate, precise, or repeatable: within-test variation is highly variable; different test environments and durations give different results; mean batch RGP values from operational RGP tests do not display strong relations to outplanting mortality or growth. We conclude that RGP has value as <u>part</u> of a stock evaluation program but it <u>must not</u> be the sole arbiter. Any interpretation of RGP test results for predicting outplanting performance must consider other information on stock condition, history, and site conditions.

INTRODUCTION

Root growth potential (RGP) has been portrayed by research as a "thermometer" of seedling quality (Ritchie 1985) The operational use is being increasingly advocated and applied (Anon. 1988).

Recent reviews (Burdett 1987; Sutton 1988) have focused on the lack of an understanding of the physiological basis for RGP. Derived stock quality interpretations are ambiguous. We take the position that this ambiguous interpretation of RGP is due to a failure to: recognize latent assumptions; unrealistic expectations; failure to specify purpose; and lack of methodological understanding of RGP. Here we expand on this position examining these previously ignored issues. We propose revised interpretations of RGP for operational purposes that are consistent with the test methodology.

HISTORY AND ASSUMPTIONS OF RGP USE

Detailed reviews of the development and use of RGP have been published (Ritchie and Dunlap 1980; Ritchie 1985; Burdett 1987). It is important to distinguish the <u>purpose</u>, <u>method</u>, and <u>interpretation</u> of RGP. RGP testing was developed in response to poor field performance of conifer seedlings as a means of predicting operational outplanting performance (Stone 1955). In spite of numerous predictive claims made about RGP, the test is only a limited potting trial. RGP is simply a test of the potential to grow roots and says nothing about outplanting survival. Making an outplanting prediction is an <u>interpretation</u> of an RGP test.

Over the last 30 years RGP testing has been applied to virtually all conifer species and stocktypes as well as some hardwood species (Ritchie 1985; Burdett 1987). In British Columbia and many other places, RGP tests bear little resemblance to the 30-day greenhouse test of Stone and Jenkinson (1971). Present tests are conducted under much shorter test durations, elevated temperatures, prolonged day lengths, and controlled environments in a variety of media (Thompson and Timmis 1978). RGP is reported to be influenced by a variety of cultural practises (Ritchie and Dunlap 1980). Stocktype (Burdett et al. 1983), genotype and provenance (Nambiar et al. 1982), and dormancy state (Johnson-Flanagan and Owens 1985) have also been implicated.

Although the test conditions and materials have changed, the interpretations of the test have not. One has only to consider the changes in nursery culture and silvicultural practise of the last 30 years to question whether the original interpretations of RGP tests remain realistic without modification.

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[1] Paper presented at the Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association meeting; 1988 August 8-11; Vernon, British Columbia.

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The operational appeal of RGP as a stock quality grading tool is based on the reported strong relation with outplanting performance (Fig. 1). The apparent simplicity and speed of the test (Day 1982) further enhances its attraction for operations.

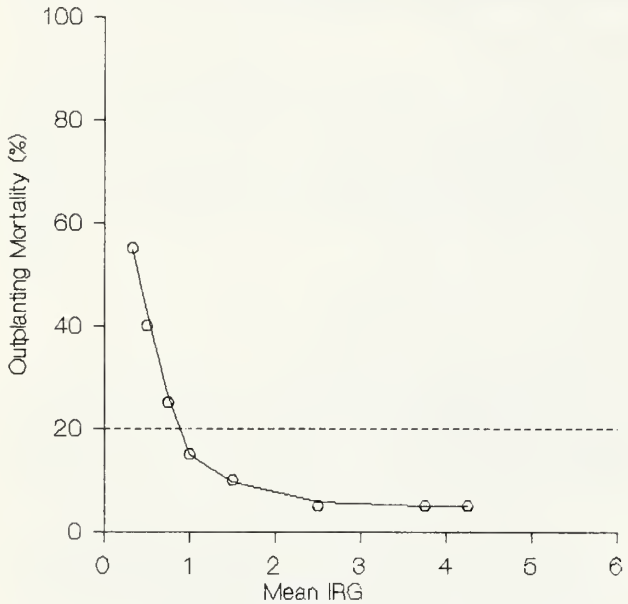

Figure 1.-- Relation between IRG and outplanting survival for bare-root lodgepole pine (after Burdett 1979, Figure 3). The horizontal line indicates an unacceptable mortality of 20%.

The fundamental assumption of RGP is quite reasonable:

> Individual seedlings exhibiting the largest number of new roots in an RGP test would have been better able to set new roots, survive, and grow in a plantation.

This assumption has led to the operational definition of the RGP test as:

> The <u>number</u> of roots initiated in a given interval of <u>time</u> under a <u>favorable environment</u> that are greater than 1 cm.

Numerous ways have been devised to test, express and interpret RGP (Ritchie 1985; Burdett 1987; Rietveld and Tinus 1987; Burr et al. 1987) but the basic methodological issues of accuracy, precision, and repeatability have not been explicitly considered. Like any measurement technique, RGP must be demonstrated to be accurate, precise, and repeatable before confidence can be placed in derived interpretations.

Before transferring this research technology to operational applications these methodological issues of accuracy, precision, and repeatability must be addressed.

ACCURACY, PRECISION, AND REPEATABILITY

Accuracy and precision are rigorously defined statistical concepts (Sokal and Rohlf 1969). Repeatability is the user-related component of accuracy and precision (i.e. observer error). These concepts are as important to the practise of statistics and conduct of laboratory technique as they are to target shooting (Fig. 2).

The accuracy, precision, and repeatability of a method determines the suitability for a specific purpose. Obviously one would wish any measurement technique to have high accuracy, precision, and give similar results regardless of who applies the test. However, useful methods may have poor precision but be accurate and repeatable enough to perform the required job.

The questions we are asking in this paper are:

1. Is RGP an <u>accurate</u> predictor of seedling vigor? (Can RGP correctly predict seedling survival?)

2. Is RGP a <u>precise</u> measurement of seedling vigor? (Is the variability of RGP measurements low?)

3. Is RGP a <u>repeatable</u> measurement? (Will several observers report the same result?)

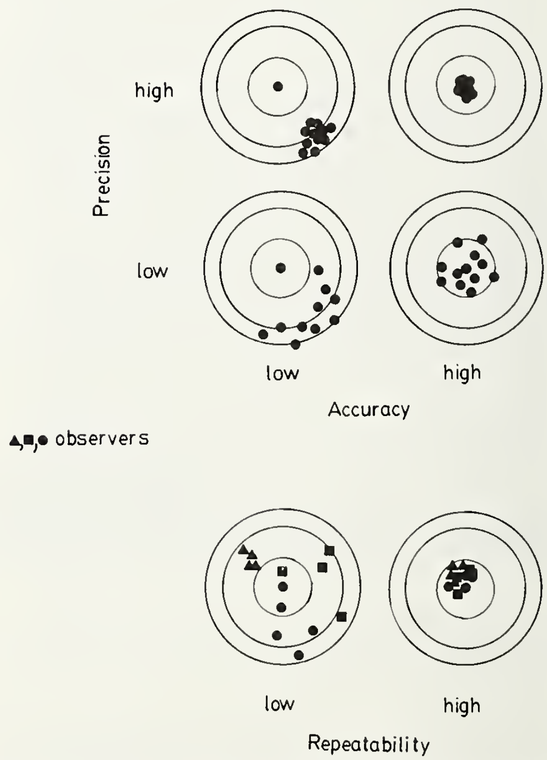

Figure 2.-- The sharpshooters analogy of accuracy, precision, and repeatability. The different shaped symbols represent different shooters.

TEST STABILITY

A common failure of RGP tests has been a lack of a standard test environment and duration. Thompson and Timmis (1978) reviewed the plethora of test environments used. New versions are published frequently (Burr et al. 1987; McCreary and Duryea 1987; Rietveld and Tinus 1987). Test environments have been described that are: sub-optimal, optimal, and too optimal. Among other factors, RGP has been shown to be influenced by test temperatures (Abod et al. 1979) and test media (Thompson and Timmis 1978). Without a clear understanding of the physiological basis of RGP, the choice of test environment and duration must be considered an arbitrary decision.

Figure 3 (Binder et *al*., in prep.) illustrates test variability in two seedlots of western hemlock. The within-test variation is high. There are large differences between test temperatures with an optimal temperature less than the 30° day/25°night[5]. Longer test durations produced more roots. "Optimal" temperatures varied among seedlots of other species tested. These results indicate that conditions of Burdett's "quick test" (Burdett 1979; 30° day/25°night for 7 days) may be too warm and short for coastal species.

The IRG differences observed under different test temperatures suggests that extrapolation from laboratory test conditions to highly variable and fluctuating, sub-optimal plantations conditions may not be reasonable. Indeed, the modest 5C° diurnal variation encountered in laboratory growth chambers is physiologically trivial compared to the 30C° diurnal fluctuation seen in many operational plantations.

Others have commented on the large within-test variability (Stone et al. 1962; Stupendick and Shepherd 1979; Abod et al. 1979; Rietveld and Tinus 1987) and have made qualifying remarks concerning the <u>research</u> interpretations drawn. Although this variation has been commented on, it has not usually been graphically portrayed (i.e. Burdett 1979; McCreary and Duryea 1987) contributing to the impression of strong relation to outplanting mortality and growth.

The reported wide range of test conditions suggests poor repeatability between different studies. The large within-test variation results and observations suggest that RGP test results have poor precision.

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[5] Unless otherwise specified all RGP tests were performed at 25C° 16 hour day of 400 $uEm^{-2}sec^{-1}$ provided by fluorescent and incandescent lamps. The 8-hour night temperature was 20C°. Tests were run for 7 days. Relative humidity of the growth chambers was 75%±5%. Tests consisted of 16 seedlings potted four to a 6" pot of 3:1 peat vermiculite adjusted to pH 5.0 with dolomite lime.

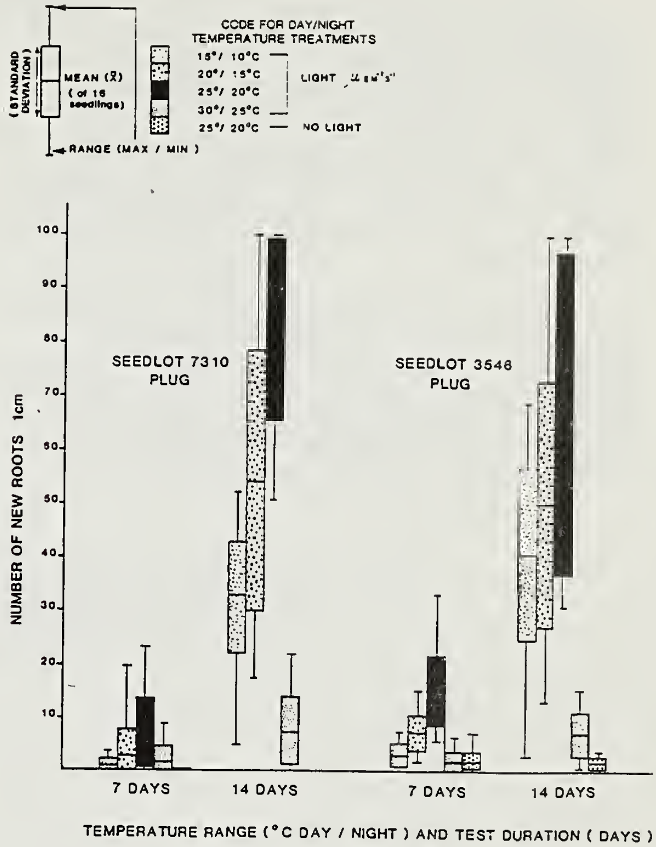

Figure 3.-- Comparison of the RGP for two seedlots of container-grown western hemlock tested under 5 test temperatures and two test durations (Binder et al., unpubl.).

NURSERY OUTPLANTING

Following Burdett et al. (1983) the British Columbia Ministry of Forests and Lands established an RGP monitoring program. Test temperatures and durations were standardized for all species (Binder, unpubl.) and nursery outplantings conducted at four nurseries. RGP tests were based on 16 seedlings. Nursery outplanting is based on plots of 50 seedlings. Twelve species and a wide diversity of stock types were examined.

The relation of IRG to nursery outplanting of 540 different batches is given in Figure 4. This figure represents 8,640 RGP tested seedlings and 27,000 seedlings in outplanting plots. No equation has been fitted through this point swarm as the large sample size makes it possible to claim statistical significance for any imaginable curve. Drawing such a line through the data gives credibility to a correlation that lacks general practical significance. The high within-test variation observed in Figure 3 also exists in this data. Including standard errors around the mean IRG values in Figure 4 would reinforce the impression of randomness.

The good news contained in Figure 4 is that only 12% of the seedlots tested had an unacceptable mortality of greater than 20%. The majority of mortality occurred within the first year of the outplanting, often within weeks of planting. One would have predicted a similar small percentage of batches would have had very low IRG. However 45% of the seedlots tested had an IRG of less than 2. There were many instances where very poor IRG resulted in very good survival and vice versa.

The nursery outplanting results question the predictive abilities of RGP and suggest poor accuracy. The high within-test variation suggests poor precision. Reported differences in testing procedures (Heywood-Farmer, pers comm.) and variation between observers conducting the test (Scagel, unpubl.) suggest poor repeatability.

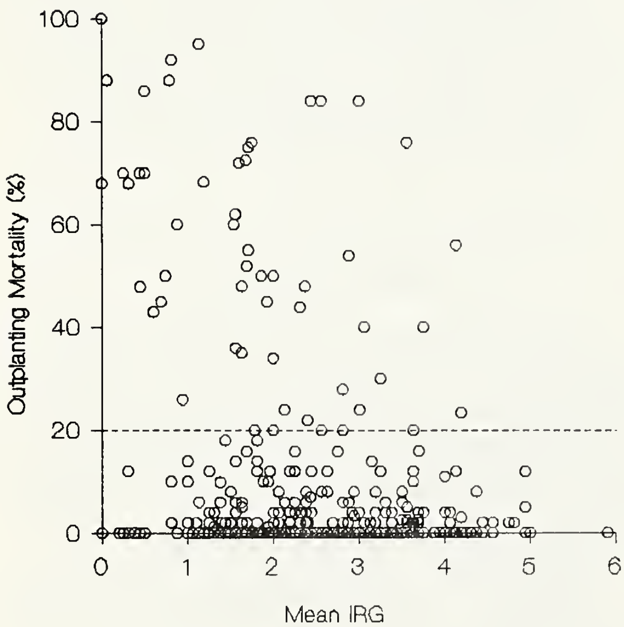

Figure 4.-- Operational IRG related to two-year nursery outplanting mortality for 540 batches of seedlings. The data includes 12 species and numerous stocktypes tested over two years by the BC Ministry of Forests Nurseries. The horizontal line indicates an unacceptable mortality of 20%. Figure 7 expresses this figure to yield interpretations of IRG given in Table 1.

CONTROLLED IRRIGATION OUTPLANTING

Although nursery outplanting plots are neither irrigated or fertilized, it has been argued that these environments are not extreme enough to indicate differential RGP-related mortality. Burdett (1987) attributes the hypothesis of site-specific RGP-related mortality to Stone (1955). That is, only stock with high RGP is capable of surviving on harsh sites, while low RGP stock can only survive on less extreme sites.

Scagel *et al.* (in prep.) examined this hypothesis in an irrigated farm field trial modeled on the work of Blake *et al.* (1979). Three irrigation regimes were used:

dry - no irrigation
fresh - irrigated every second week
moist - irrigated every week

Three stocktypes of the same seedlot of coastal Douglas-fir grown at a single nursery were used. Several liftings of seedlings were made in expectation of realizing a wide of IRGs (Figure 5). A wide range of IRGs were obtained.

Figure 5 illustrates the two-year outplanting mortality for each of the irrigation regimes. The within-test variation was similar to that presented in Figure 3. There was no consistent ranking of stocktype-liftdate mortality over the three irrigation regimes. Longer storage was associated with a decreased IRG but was of no consequence to general survival. As observed in the nursery outplanting plots, most death occurred within the first year - most death within weeks of planting.

The only suggestion of a relation between outplanting mortality and IRG occurred on the dry site. On the dry site all stocktypes and lift dates had unacceptable mortality. Unacceptable mortality also occurred on the other two sites. There were no IRG-related relative growth differences but there were large site-related growth and form differences.

The physiological impediments to seedling survival and performance imposed by the plantation environment are critical considerations in stocktype selection and stock quality evaluation. Quality is fitness for purpose (Sutton 1980). These results suggest RGP offers only limited prediction of seedling survival. These predictions might be applicable to extreme environments but the within-test variation mediates against such strict interpretation. Although RGP may have some accuracy, the precision is low.

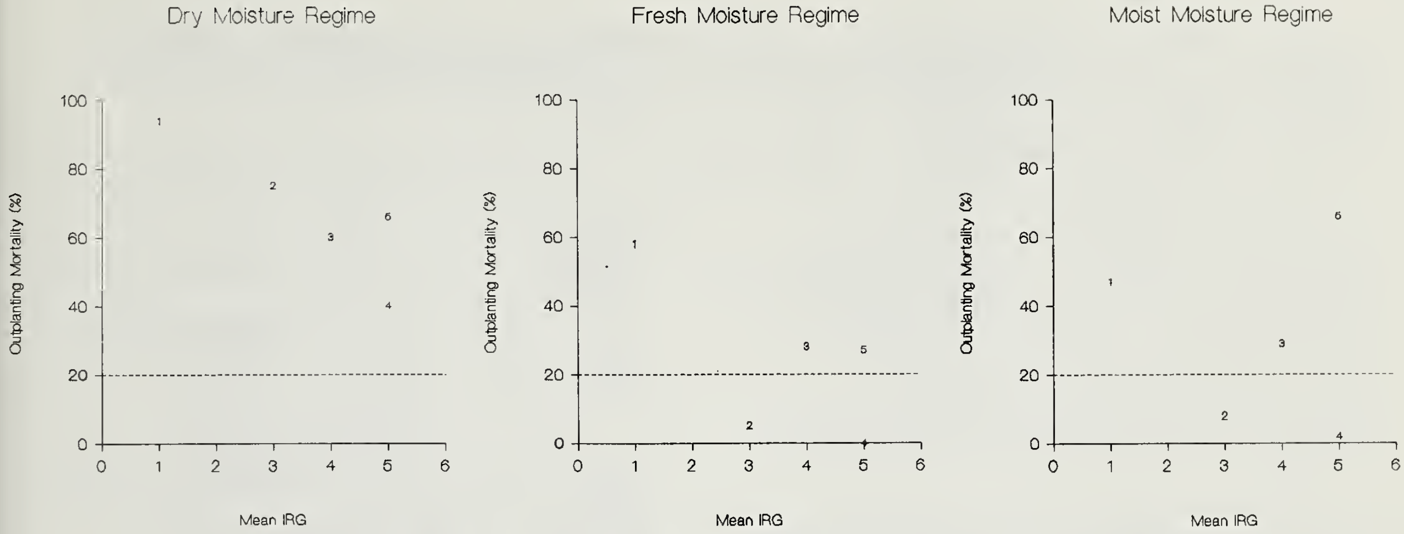

Figure 5.-- Mean IRG of various liftdates and stocktypes of Douglas-fir related to two-year mortality in three controlled environments. The horizontal line indicates an unacceptable mortality of 20%. 1, January-lifted plug-transplant; 2, January-lifted 2+0 bareroot; 3, December-lifted PSB 313; 4, January-lifted PSB 313; 5, February-lifted PSB 313.

OPERATIONAL OUTPLANTING

The acid-test of the utility of RGP as a stocky quality grading tool is <u>not</u> how well the test predicts outplanting mortality under carefully controlled research trials. The utility of the test is determined under operational plantation conditions.

Scagel et *al.* (in prep.) followed three seedlots of coastal Douglas-fir over a range of operational plantation environments on southern Vancouver Island. The sites studied were all suitable for Douglas-fir. The seedlots followed had very similar, high IRGs. According to the RGP test interpretation, these seedlots would be expected to have low mortalities.

The two-year outplanting mortality is given in Figure 6. The within-test variation was similar to that shown in Figure 3. Half of the plantations had an unacceptable mortality but there was little mortality observed in the nursery outplanting trials. As observed in nursery outplanting plots and irrigated field conditions, most mortality occurred within the first year - usually within weeks of planting. Excavation of dead and poorly growing seedlings indicated that microsite selection and site preparation were the primary factors determining mortality. Unlike mortality, growth correlated with plantation ecosystem. Inspection of planting reports indicated that there had also been delayed planting with attendant stock handling problems.

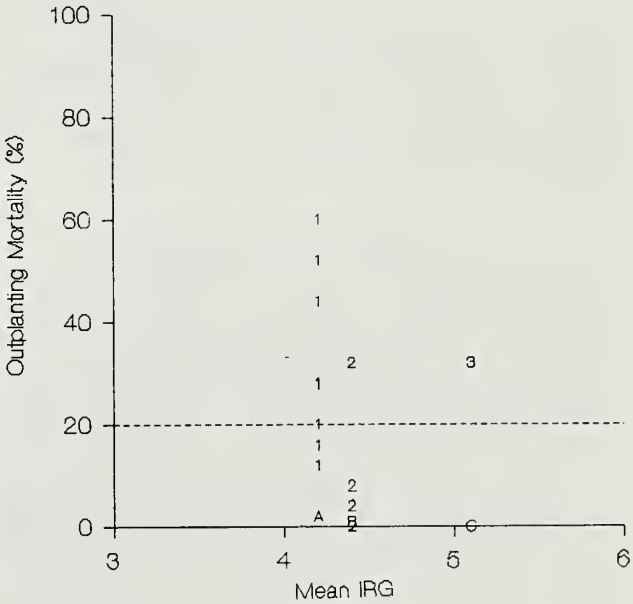

Figure 6.-- Mean IRG of three Douglas-fir seedlots related to two-year operational outplanting mortality in commercial plantations and nursery outplanting plots. The horizontal line indicates an unacceptable mortality of 20%. 1, 2+0 bareroot; A, nursery outplanting mortality of 1; 2, 2+0 bareroot; B, nursery outplanting mortality of 2; 3, 1+0 PSB 313; C, nursery outplanting mortality of 3.

These observations suggest that RGP differences can be equalized by stock handling and planting. This conclusion should not be surprising as there is no substitute for careful handling and storage, good planting, microsite selection, and microsite preparation.

These results iterate Landis and Skakel's (1988) comments about RGP being only a point estimate of stock quality. That is, the results of an RGP test are felt to be representative for the population at the time the sample was drawn and the test run. A lot of stock handling problems can occur in the two weeks it takes to run an RGP potting trial (Edgren 1984). Operationally, any predictive ability of an RGP test can be very quickly altered by poor handling practises.

The same conclusions about accuracy and precision are also clear: RGP appears to have poor accuracy and precision. In addition it may not be fast enough for operational silvicultural purposes. The lack of precision and accuracy under operational conditions suggests the test lacks general utility - although this does not mean that the test lacks specific, or special purpose, utility such as for research.

RGP USE

A planted, poor quality seedling can cost triple a mistakenly destroyed acceptable seedling. The silviculture cost increases even more if the costs are considered interest-bearing and the plantation requires replanting. RGP-mediated culling decisions should respect this economic consideration and strive to reject unacceptable seedlings.

"Seedling quality" is hard to define, difficult to quantify and impossible to make error-free culling decisions. There will always be instances where some of the good is thrown out with the bad and vice versa (Figure 7). This does not mean that seedling quality is not worth investigating. To minimize the acceptance of otherwise low vigor seedlings, both purpose and fitness must be stated.

RGP has value as part of a stock evaluation program but on its own offers only circumstantial evidence about seedling quality. RGP can suggest that seedling quality may be poor, but cannot provide explanations, solutions, or predictions of field performance. Other sources of information about the stock and the environment of the planting site are required before a stock quality judgement can be made.

In our experience, RGP tests have proved valuable when stock had been suspected of being poor quality as a result of other information on cultural or storage conditions. In these instances additional information on stock quality was critical in flagging suspect batches, repeated potting trials of large number of seedlings corroborated the suspicion, and additional information provided explanations for poor seedling quality.

Like a traffic light, we propose three general decision-making procedures be considered in interpreting the results of an RGP test (Table 1): reject, reserve, caution. These procedures reflect our position that RGP may have value only where extreme values are reported. Figure 7 emphasizes the chances of accepting poor quality batches. There is always a chance of accepting poor vigor stock - 10% of the high IRG batches had an unacceptable mortality.

Regardless of the test results the test conditions and variability within the test should always be considered. We recommend that other sources of information about stock should be routinely considered even though they are indicated in Table 1 as optional. Many physiological and morphological tests have been devised and can be used (Duryea 1985). Knowing the cultural and storage history of the stock is the most important. As well, the plantation environment and the expected physiological impediments to plantation establishment in these environments must be considered.

Returning to the sharpshooters' analogy (Fig. 2), RGP is like a small caliber shotgun not a target pistol. It should be used accordingly.

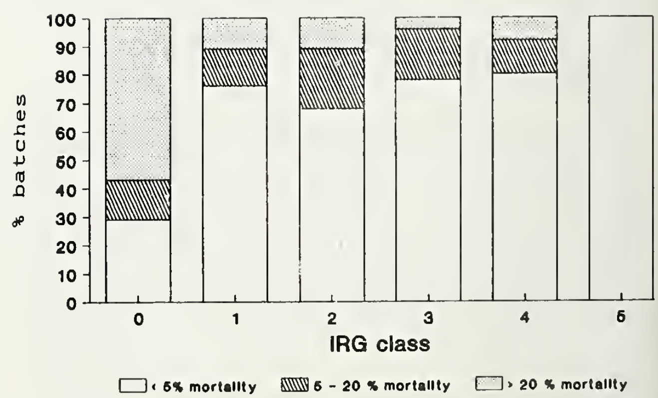

Figure 7.-- IRG interpretation for silvicultural risk. Figure 4 re-expressed to indicate mortality of a mean batch IRG. Mortality is based on nursery outplanting results.

Table 1 -- Decision making recommendations concerning RGP test results. Data are based on 540 operational RGP tests and nursery outplanting plot results. These results pool all species and stocktypes.

	RGP Interpretation Status		
	Red	Yellow	Green
Decision	Automatic rejection	Reserve decision Consider other info	Caution
Parameters			
mean IRG[1]	0	<2	>2
Chance of accepting an unacceptable batch[2] See Figure 7.	<1%	50%	10%
Additional stock information requirement	Not usually required	Required	Maybe
Type of information			
Test conditions	+	+	+
Purpose	(+)	+	(+)
Pathology	(+)	+	(+)
Morphology	(+)	+	(+)
Physiology	(+)	+	(+)
Storage history	(+)	+	(+)
Cultural history	(+)	+	(+)

[1] IRG from Burdett (1979).
[2] "unacceptable" is considered greater than 20% mortality in a nursery outplanting plot. Actual plantation conditions could require adjusting IRG limits.
+ collect other information; (+) other information optional.

SUMMARY

Under present operational testing regimes the accuracy, precision, and repeatability of RGP is low enough that stock quality assessments performed solely on RGP are suspect. An RGP test does not absolve the forester or nurseryman from the responsibility of looking closer at the seedlings that are being purchased - particularly during their nursery tenure. Combinations of methods as well as cultural and silvicultural considerations must be used in decision-making processes concerning stock quality.

Owing to the inconsistency and variability of RGP test results, one must question whether predicating the utility of other methods of assessing stock quality on a comparison to RGP is appropriate. We also question the appropriateness of transferring research technology with these limitations to a fully operational stock evaluation program.

These conclusions are not surprising as seedlings are sensitive to temperature, moisture, nutrients, and aeration. This sensitivity is exploited daily in a nursery environment. How seedlings respond to their environment is a function of their cultural history and current developmental state. Rigorous stock evaluation must consider the dynamic and interdependent nature of biological systems. To assume otherwise is to consider seedlings little more than widgets.

ACKNOWLEDGMENTS

This project is funded under the Canada British Columbia Joint Forest Resource Development Agreement (FRDA 2.02). We would like to thank the many nurserymen and field silviculturalists who have gone out of their way to discuss these ideas with us and in particular Ev van Eerden.

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Root Growth Capacity Effects on Field Performance[1]

David G. Simpson, Alan Vyse, and C.F. Thompson[2]

Abstract.--Good field performance (first year survival) was found for interior spruce (Picea glauca x engelmannii) or lodgepole pine (Pinus contorta) seedlots that had average root growth capacity (RGC) levels greater than 10 new roots longer than 10 mm per seedling. The RGC-field survival relationship was affected by both species and planting year, but not so much by planting site.

INTRODUCTION

Since 1977 forest nurseries in British Columbia have routinely determined the root growth capacity (RGC) of batches of nursery stock. The method used is similar to that described by Burdett (1979). For the major species planted in British Columbia, correlations between RGC and field performance (survival and/or growth) are often found (Burdett et al. 1983; van den Driessche 1983; Simpson unpubl.).

Beyond merely assuming that a higher level of RGC is better than a lower level, interpretation of RGC test results has been difficult. A number of factors act to confound interpretation including: sampling problems, large tree-to-tree variation, suitability of test duration and conditions, uncontrolled or unknown variations in other physiological and morphological characteristics which may affect field performance, and interactions with planting site environment.

The purpose of this experiment was to determine the nature of the relationship between RGC and field performance for interior spruce (Picea glauca x engelmannii), lodgepole pine (Pinus contorta) and interior Douglas-fir (Pseudotsuga menziesii var. glauca) on a range of ecologically different forest planting sites in British Columbia's southern interior.

THE EXPERIMENT

To establish relationships between RGC and field performance, it is necessary that batches of stock ranging in RGC from none to many roots per plant are available and that these batches of stock are planted at the same time and on the same planting site.

In this experiment, batches of stock with a wide range of RGC were obtained from cold storage after reviewing the BC Ministry of Forests' RGC testing results. For each species (interior spruce, lodgepole pine, and Douglas-fir) 20 to 30 batches of stock (seedlots) were identified and shipped to the Kalamalka Research Station near Vernon, B.C. The stock was re-packaged and RGC re-measured shortly prior to establishment of outplantings.

The RGC testing procedures were similar to those described by Burdett (1979). Seedlings were potted in 3:1 peat-vermiculite soil mix and grown for 7 days in conditions providing 18-hour days (400 $\mu mol/m^2/s$), 30°C-day and 25°C-night temperatures. The root growth assessment procedures differed only in that the total number of newly elongated roots longer than 10 mm on each seedling was recorded.

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[1]Presented at the Western Forest Nursery Council - Forest Nursery Association of BC meeting, August 9-11, 1988, Vernon, B.C. Canada.

[2]The authors are research scientists with the B.C. Ministry of Forests at Vernon, Kamloops, and Nelson, B.C. respectively.

Between 1985 and 1987, 18 plantations were established on a range of forest site types in British Columbia's southern interior (table 1). Each outplanting consisted of three blocks with 20 to 30 rows of 25 seedlings. The order of rows was randomized within each block.

Table 1.--Outplanting sites

	Site Type[1]	Planting year
Interior spruce	ICHe2	1985
	ICHm1	1986
	ESSFm	1986
	ESSFd4	1986
	MSB1	1987
	ESSF	1987
	ESSFm	1987
Lodgepole pine	ICHm1	1986
	ESSFd4	1986
	ICHm2	1987
	ICHa1	1987
Douglas-fir	IDFb	1986
	IDFb	1986
	ICHm2	1986
	IDFb	1987
	IDFb	1987
	ICHe2	1987
	ICHa1	1987

[1]Site types as described by the biogeoclimatic system used by the B.C. Ministry of Forests.

RESULTS AND DISCUSSION

In most cases the relationship between RGC and first year field survival for interior spruce and lodgepole pine but not interior Douglas-fir was asymptotic in shape (for example, fig. 1). Regression lines could be drawn through these scatter of points to indicate the proportion of survival variation that is a function of variation in RGC. While these type of curves are useful to show the nature of the relationship between RGC and field survival, they are not as useful for interpreting RGC data or more simply for determining an acceptable level of RGC for batch culling.

A more useful approach may be to consider various RGC threshold levels and then to examine the field survival of batches above and below those thresholds. The data in figure 1 suggest for those plantations a natural threshold exists at around a RGC level of 10 roots per plant.

When a threshold of 10 roots greater than 10 mm per plant is applied to the data obtained in this experiment (figure 2) the following observations can be made:

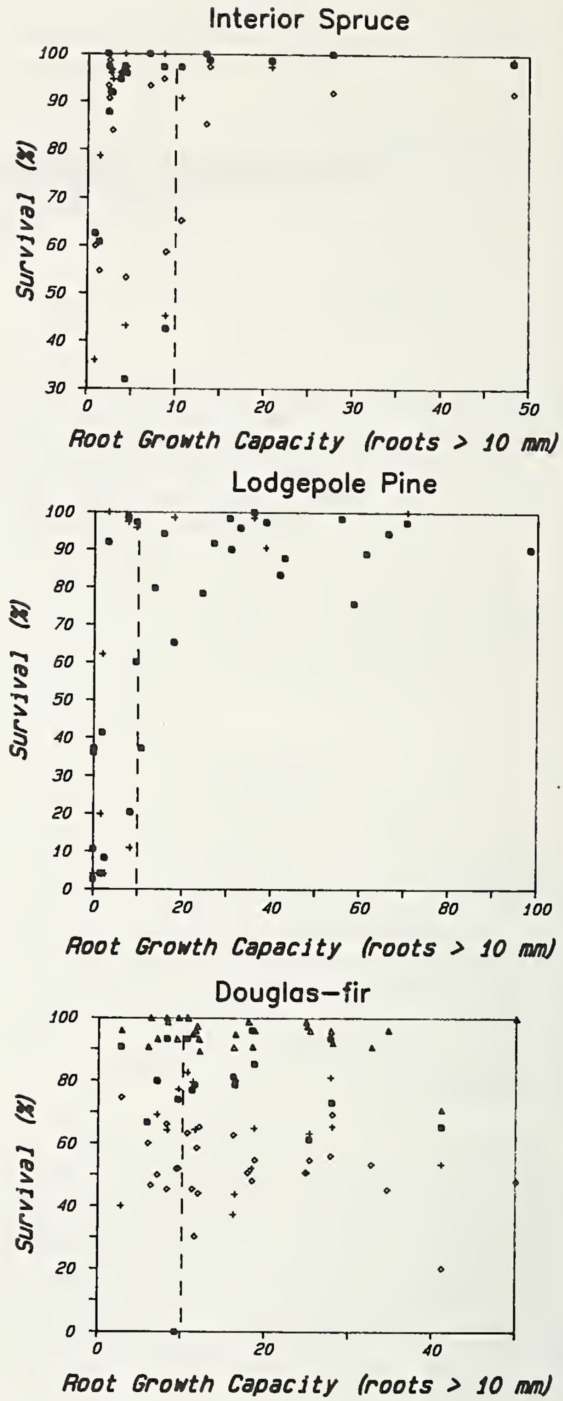

Figure 1.--First year field survival (%) of interior spruce, lodgepole pine, and Douglas-fir seedlings planted in 1986. Each point represents the mean RGC of a 20-seedling sample and the mean field survival of 75 seedlings.

1. planting batches of stock with RGC levels greater than an average 10 roots per plant results in generally higher survival with less variation or chance of poor survival.

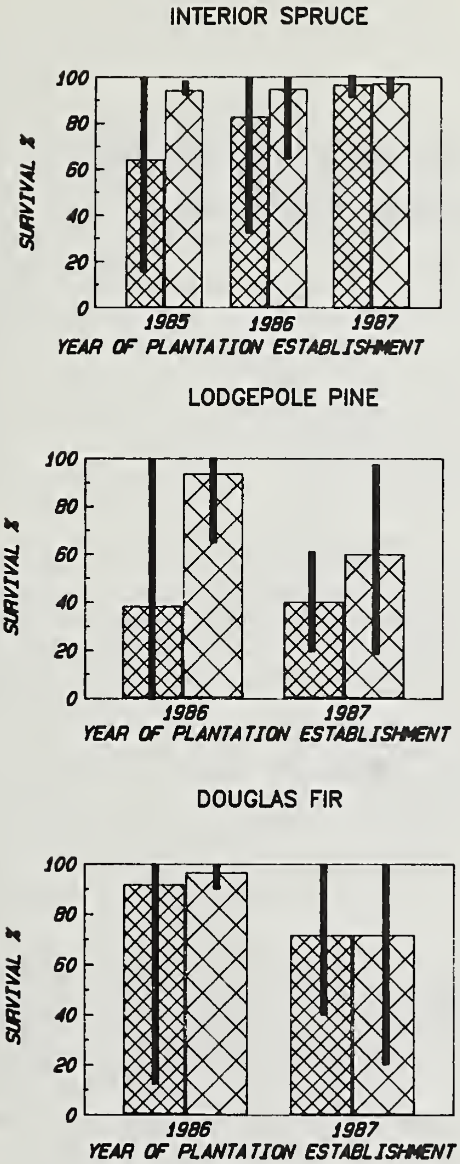

Figure 2.--First year field survival (%) of interior spruce, lodgepole pine, and Douglas-fir planted between 1985 and 1987. Bars represent mean RGC for seedlots with RGC's less than 10 roots per plant (narrow cross hatch) and greater than 10 roots per plant (wide cross hatch). Range of seedlot means is indicated.

2. there is an interaction with planting season; in some years RGC is not of predictive value in determining field performance.

3. there is a species interaction wherein the relationship between RGC and survival for both interior spruce and lodgepole pine seems similar, but there seems to be no relationship in Douglas-fir between RGC and survival. It is unclear why no relationship between RGC and Douglas-fir survival was found.

4. The RGC-survival relationships, at least for the first year, are little affected by planting site.

CONCLUSION

The data presented here suggest a natural RGC threshold of an average 10 roots per plant greater than 10 mm in length could be used as a batch culling guideline to ensure higher survival and less chance of plantation failure for interior spruce and lodgepole pine planted in British Columbia's southern interior. Barring unusual circumstances, seedlots whose RGC levels are greater than an average 10 roots per plant will survive very well on outplanting.

Due to the large survival variation in seedlots planted with RGC levels less than 10 roots per plant, it is expected that such a threshold, or batch cull level, if implemented in practice will result in destruction of some batches of stock which might in some circumstances have adequate field performance. The cost-benefit of batch culling based on low RGC levels should therefore be considered very carefully by forest managers before embarking on such a program.

Rather than using a batch culling program based on RGC (or some other aspect of stock quality), it would be more constructive to manipulate nursery cultural, cold storage, and stock handling practices to ensure that no batches of stock have RGC levels less than 10 roots per plant.

The results presented also support the need for further investigation of other stock quality measures to augment the widespread use of RGC testing.

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The Effects of Elevated Post-Storage Temperatures on the Physiology and Survival of White Spruce Seedlings[1]

W.D. Binder[2] and P. Fielder[3]

Abstract.--The objectives of this study were to determine the effects of elevated temperature and exposure time on the physiology and survival of post-cold stored white spruce (*Picea glauca* (Moench) Voss.) seedlings, and whether such effects could be detected quickly physiologically prior to planting. Foliage and root temperatures lagged behind ambient temperatures after transfer from storage (-2°C), to thawing (5°C), and from thawing to heat treatments (10, 20, 30, 40°C). Although no visible seedling damage was apparent after 12 h at 40°C, damage was 32% after 24 h. Seedling mortality was 48% after 48 h, and reached 100% after 72 h. At 30, 20 and 10°C no seedling mortality was observed for 24, 72 and 96 h respectively. Root Growth Capacity was poor in treated seedlings showing poor survival after planting. Seedling mortality of over 10% from elevated temperatures may be detected in about 24 h from specific conductivity of tissue leachates. This test, however, does not predict significant non-lethal heat stress tissue damage of seedlings prior to planting. Exposure of seedlings in boxes to temperatures above 10°C is not recommended.

INTRODUCTION

Survival of conifer seedlings after planting depends on their physiological state prior to storage, at the time of planting, and upon planting site conditions (Ritchie 1984; Duryea 1985). After lifting seedlings may be culled, counted, stored, loaded in and out of transporters, temporarily stored in the field and finally planted (Trewin 1978). During these operations seedlings may be exposed to a range of stresses including drying or freezing, mechanical damage to shoots and roots through impact (Trewin 1978; Tabbush 1986), and heating (DeYoe et al. 1986).

Exposure of conifer seedlings to heat may have a number of effects on seedling physiology and subsequent survival including stress metabolism (Haard 1983), excessive expenditure of food reserves (Mattsson 1986; Ritchie 1984; Puttonen 1980, 1986), and loss of cold hardiness (Levitt 1980). Stress due to heat increases with temperature and duration of exposure (Levitt 1980).

Although extreme heat results in rapid, extensive tissue death, the effects of more moderate heat stress on seedling vigour are not always visible and are usually only manifested after the stock has been planted (Kauppi 1984). Determining seedlings vigour status using potting trials often takes too long for the nurseryperson to make a decision about stock quality before shipment to the planting site. However, some physiological attributes may be detected which reveal relationships between stock quality and subsequent survival after planting (Wakely 1948; Zaerr 1985).

This study reports: i) the amount of heat stress which can be applied to white spruce seedlings after cold storage without a decrease in survival or vigour, ii) and whether the results of heat stress can be detected by physiological tests prior to planting. Results indicate the tolerance of the test seedlot to heat stress during thawing, pre-shipment storage, transportation, or storage at the planting site.

[1] This paper was presented as a poster at the Combined Western Forestry Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association Meeting; 1988 August 8-11; Vernon, British Columbia.

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METHODS OF INVESTIGATION

General

White spruce 1-0, PB313 styroblock containerized seedlings (seedlot Sw, 8504, 87G09005), destined for spring planting in north-eastern British Columbia, were grown under operational conditions at a nursery near Vancouver, British Columbia in 1987. Seedlings were lifted in late November 1987 and cold stored (-2°C) at the Ministry of Forests, Research Laboratory, Glyn Road, Victoria, B.C.

Waxed cardboard boxes (36x14 in.) were lined with a wax paper bag and seedlings were packed, 500 to a box in bundles of 20 with plugs wrapped in plastic. Boxes were then sealed with tape so that they could be reopened to remove samples.

In the spring of 1988 physiological measurements were made during two time intervals because of the short sampling period and available growth chamber space. Each period included an 8-day thaw at 5°C followed by up to 96 h heat. The first sample period began on April 11, 1988 and the second on April 26.

Samples were taken of frozen seedlings, and seedlings which had been thawed for 8 days. Following the thaw period seedlings were placed into the randomly assigned temperature treatments, 5, 10 and 40°C during the first experimental period and 20 and 30°C during the second. Seedlings were sampled and measured after 12, 24, 48, 72, 96 h.

The temperature inside boxes was recorded constantly throughout the experiment with thermistors monitored by a Campbell CR10 datalogger. Each box contained three temperature probes measuring foliage, and root temperatures of inner and outermost seedling bundles.

Each temperature treatment was represented by only one growth chamber because of limited equipment availability.

Specific Conductivity of Leachates

The amount of electrolyte leakage from tissues is a relative measure of the degree of cell membrane damage caused by exposure of seedlings to stress (i.e. low or high temperatures). The method used here is modified from van den Driessche (1976) and Burr et al. (1986).

Measurements were made after 24, 48, 72 and 96 h. Fifteen seedlings were divided at random into three replicates of five seedlings. The middle 8 cm section of stem of each seedling was cut into 15, 0.5 cm stem segments. Three segments were randomly selected from each of the five seedlings and placed in a covered test tube.

Needle segments 1 cm long, cut at both ends, were taken from one side of the stem of each seedling. All needles removed from one seedling were mixed and subsamples of needles from each of five trees in each replicate combined to give an approximate final weight of 0.7 g.

During preparation the stem and needle segments were kept in small plastic petri dishes on moist filter paper before transferring them to test tubes. Deionised water was added to the tissue segments in a ratio of 10:1 by weight. The specific conductance of the leachates were determined with a Radiometer CDM83 Conductivity meter after 24 h in a water bath at 25°C.

Root Growth Capacity

Root Growth Capacity (RGC) tests were conducted on 16 seedlings removed; i) directly from cold storage ii) at time zero of the treatment period (end of thaw) and, iii) after 48 and 96 h. For the 20 and 30°C heat treatments testswere also conducted after 24 h. Test conditions were carried out according to B.C. Ministry of Forests standards for white spruce, (400 μ mol^{-2}.s^{-1}, 30°C day/25°C night, 75%RH and a 16 h light period. Pots, containing a peat/vermiculite mixture (pH 5.7) were watered to field capacity at time zero and after 5 days. After a test period of 7 days the numbers of roots >1 cm produced during the test were counted and the Index of Root Growth calculated (IRG) (Burdett 1979).

Survival of Heat Treated Seedlings

Immediately after treatment seedlings were planted on site at the Glyn road Research Laboratory. Seedlings were planted in a completely randomized design. No water or fertilizer was applied.

Seedlings were evaluated for mortality and damage two months after planting. A seedling was considered dead if needle damage extended over the whole shoot. Damage (between 10 and 90%) to each seedling was scored as a percentage of the total plot sample (50 seedlings) if the seedling was not dead.

RESULTS AND DISCUSSION

Temperature inside boxes did not immediately reach target levels (Figs. 1 and 2). This lag time, may account for the surprising tolerance of this seedlot at the highest heat treatment. The 40°C treatment temperature was not reached until almost 20 h after treatment started, but was about 36°C within 6 h (Fig. 1) and over 30°C within 3 h. There can also be a differential heating rate up to 8 h between outer and inner bundles in an box (compare Fig. 1 to Fig. 2).

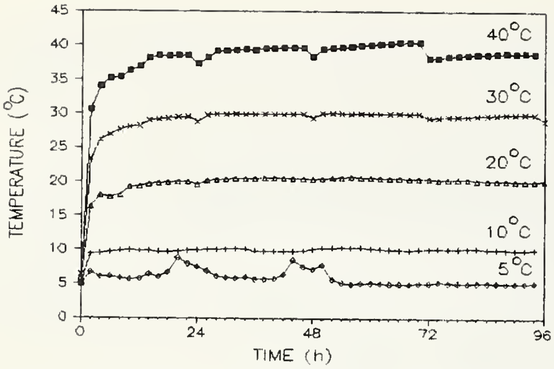

Figure 1. Foliage temperatures (°C) inside boxes during both experimental treatment periods, from April 18-22 (40, 10, and 5°C) and May 02-06 (20 and 30°C).

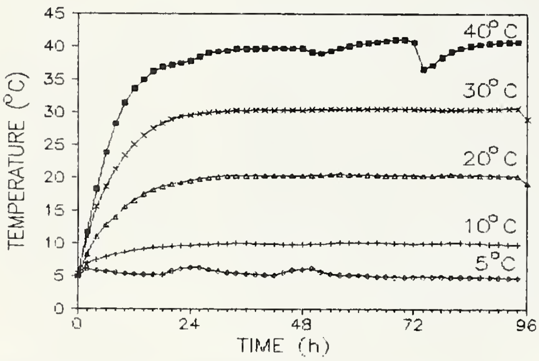

Figure 2. Root temperatures (°C) inside boxes during both experimental periods, from April 18-22 (40, 10 and 5°C) and May 02-06 (20 and 30°C). A bundle from the centre of the box was monitored.

Survival

Table 1 shows the percentage of damage (D) and mortality (M) of treated seedlings 2 months after planting on a moist site. Mortality was <4% and there was no damage to live seedlings which were planted after removal from cold storage (-2°C), and after thawing at 5°C for 8 days. After 96 h at 5, 10 and 20°C mortality was <10% and damage was zero.

Mortality and damage increased with length of treatment at 30 and 40°C. At 30°C mortality was <10% up to 48 h but increased to 18 and 40% at 72 and 96 h. At 40°C visible damage was observed at 24 h and mortality was 48% by 48 h and 100% by 72 h.

Root Growth Capacity

Figure 3 shows that the Index of Root Growth (IRG) was acceptable by operational standards over the thawing period and there was no significant

Table I. Percentage of field mortality (M) and damage (D) to white spruce seedlings resulting from heating for up to 96 h. Dashes indicate damage or mortality was <4%.

	TEMP. (°C)	DURATION OF TREATMENT (H)											
		0		12		24		48		72		96	
		M	D	M	D	M	D	M	D	M	D	M	D
THAW	5	-	-	-	-	-	-	-	-	-	-	-	-
HEAT	5	-	-	-	-	-	-	-	-	-	-	6	-
	10	-	-	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-	8	-	6	-
	30	-	-	-	-	6	16	4	-	18	16	40	20
	40	-	-	-	-	4	32	48	4	100	--	100	--

change over the treatment period at 5, 10 and 20°C. At the start of the heat treatments IRG was about 3.5, after 48 h at the 30 and 40°C treatments IRG had decreased to 2.5 and to 0.2 respectively. Only a slight decrease in IRG was noted in seedlings which received 20°C for 96 h, but IRG decreased to 0.5 at 30°C and was zero at 40°C.

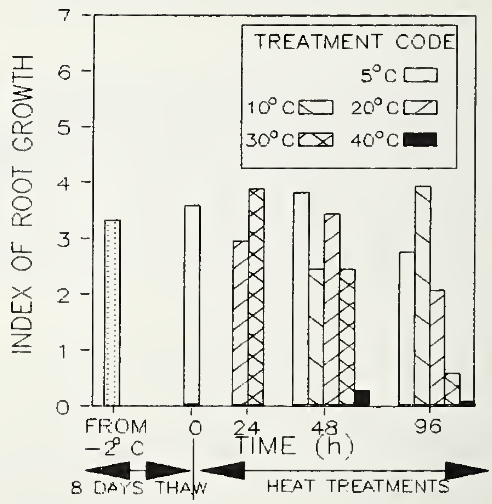

Figure 3. Index of Root Growth (IRG) of white spruce seedlings after treatment at five storage temperatures (5, 10, 20, 30 and 40°C) for up to 96 h.

Figures 4, 5 and 6 show roots on seedlings at 10°C and 30°C for 96 h and 40°C for 48 h. Seedlings in the latter two temperature treatments had visible shoot damage compared with those which were held at 10°C for 96 h. A comparison of Table I and Figure 3 indicates that IRG data seem to reflect quite well the field survival results.

Figure 4. Root development after an RGC test of seedlings previously treated to a 10°C storage temperature for 96 h. There was no visible damage to stems or needles. Buds were flushing.

Figure 5. Root development after an RGC test of seedlings previously treated to a 30°C storage temperature for 96 h. Considerable discolouration of stems and needles was noted in some seedlings. Buds were not flushing.

Figure 6. Root development after an RGC test of seedlings previously treated to a 40°C storage temperature for 48 h. Discolouration in many stems and needles was severe. Buds were not flushing.

Specific Conductivity

Specific conductivity of leachates from stem segments increased with length of treatment and temperature (Fig. 7). At 40°C specific conductivity increased after 48 h indicating cell damage (Fig. 7). At 20 and 30°C cell damage occured after 72 h treatment. (Actual temperatures inside boxes are shown in Figures 1 and 2).

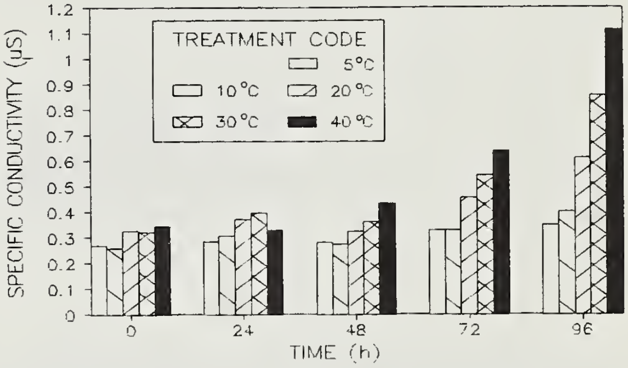

Figure 7. Specific conductivity (uS) of leachates from stem segments of white spruce after holding intact seedlings in five treatment temperatures up to 96 h. Segments were soaked in 10 times their fresh wt. (g) of deionised water for 24 h.

Specific conductivity of leachates from needle segments (Fig. 8) increased in 30 and 40°C treatments indicating tissue damage after 72 h. At 20°C an effect, although slight, was also noted after 72 h. However, this did not increase further after 96 h. At 5 and 10°C no change occurred up to 96 h.

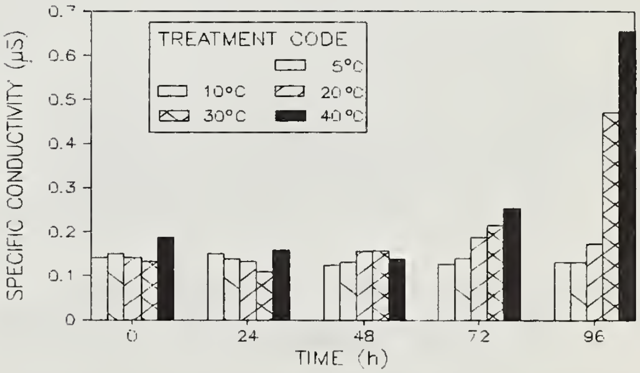

Figure 8. Specific conductivity (uS) of leachates from white spruce needle segments after holding intact seedlings in five treatment temperatures for up to 96 h. Segments were leached into 10 times their fresh wt.(g) of deionised water for 24 h.

Measurement of leachate conductivity from tissues may be useful to assess stock quality quickly (24 h) after damage from excessive heating. Conductivity has been used to assess other types of physiological stress e.g. frost damage (Colombo *et al*. 1984) for some time. However, the test at present seems to lack sensitivity. Below 48 h heat treatments did not result in a detectable increase in leachate conductivity (Figs. 7 and 8) despite significant visible seedling damage after outplanting (see 30°C after 24 h, Table 1). Results indicate mortality of greater than 10% is detectable. However, the amount of leachate detected increases with time within a specific treatment temperature and continues to increase even after mortality has reached 100% (c.f. Table 1 and Figures 7 and 8 at 40°C at 72 and 96 h). Measurement of leachates from stem segments appears to be a more sensitive indicator of heat damage than from needle segments.

ACKNOWLEDGEMENTS

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245

Variable Chlorophyll$_a$ Fluorescence and its Potential Use in Tree Seedling Production and Forest Regeneration[1]

W. Vidaver,[2] P. Toivonen,[3] G. Lister,[4] R. Brooke,[5] and W. Binder[6]

Abstract.--An integrating fluorometer for detection of variable chlorophyll$_a$ fluorescence has proven useful in determining the physiological status of conifer seedlings. Information obtained can be used in selecting lifting dates, in evaluating post-storage vigor and in assessing the effectiveness of nursery watering and fertilizer regimes.

INTRODUCTION

Radiation incident on a seedling canopy or leaf can be absorbed, reflected or transmitted (Fig. 1). Of the incident photosynthetically active radiation (PAR 400 - 700 nm) the leaf absorbs about 90%. The absorbed energy may be used by the photochemical system to fix carbon, be dissipated as heat or emitted as fluorescence. The energy of fluorescence emission *in vivo* represents only about 3 - 5% of the excitation energy. Variable chlorophyll$_a$ fluorescence (Fv) is closely linked to the photochemical activity of the chloroplasts and therefore can be used as a non-destructive probe of the photochemical/photosynthetic processes. These processes are influenced by many factors including the plant's status with respect to water (watering regime), nutrients (fertilizer treatment), temperature (seasonal, diurnal) and light (daylength and irradiance level).

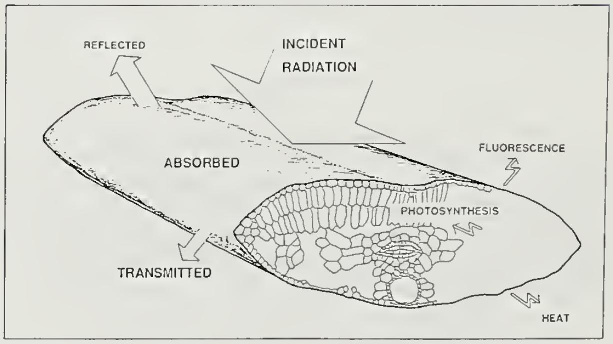

Figure 1.--Schematic drawing of a western hemlock (conifer) needle section. Disposition of the incident light (PAR) is proportional to the size of the arrows. It is this fluorescence that is the basis of Fv measurement. (Redrawn in part from Tucker and Emmingham, 1977).

MATERIALS AND METHODS

Measurement

Seedlings are dark-adapted for 15 to 20 min prior to Fv measurement. This is required to ensure an initial zero photochemical activity and CO_2 fixation state. The shoot of the dark-adapted seedling was then placed in the spherical cuvette of the integrating fluorometer (Fig. 2) (Toivonen and Vidaver, 1984) interfaced to a computer for data acquisition and analysis of Fv. Gas exchange was measured with an ADC Mk III infra-red gas analyzer

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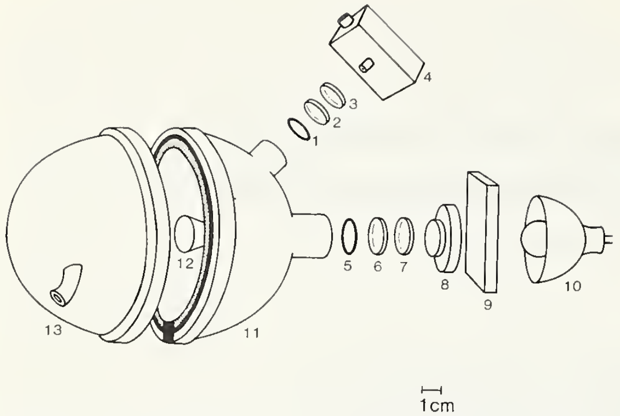

Figure 2.--Exploded view of the integrating fluorometer probe. (1) rubber O ring, (2) CS 7-59 filter, (3) CS 2-64 filter, (4) optical detector assembly, (5) O ring, (6) CS 4-96 filter, (7) CS 3-71 filter, (8) photographic shutter, (9) heat absorbing filter, (10) Sylvania EFP (100 W, 12 V) projector lamp, (11) supporting hemisphere (it supports the light and detector assembly and is fitted to a stand), (12) dispersion cone, (13) detachable hemisphere. (Reproduced from Toivonen and Vidaver, 1984).

(IRGA). Dry wt. was determined by oven drying samples at 90^{o} C for 24 h. Unless otherwise stated all Fv and gas exchange measurements were carried out at 22 - 25^{o} C.

Normalization

Once data are collected, the fluorescence (Fv) transients need to be compared. The Fv transients (curves) are normalized to compensate for differences in chlorophyll content (ie. plant size) (Fig. 3). The normalization formula uses a value for instantaneous fluorescence (F_o) (see Papageorgiou, 1975 for a review of variable chlorophyll fluorescence).

The formula is:

$$Fv = \frac{F_{\vartheta} - F_o}{F_o}$$

where Fv is normalized variable fluorescence at time t,
F_{ϑ} is non-normalized fluorescence at time t,
and F_o is O-level fluorescence

Averaging

To evaluate a seedling population or seedlot, a normalized Fv transient or induction curve for each of several seedlings is used (Fig. 4). Each curve represents more than 1000 data points obtained at a predetermined frequency over a fixed time period. Averaging is done by summing the values at each sampling point of the normalized curves, then dividing by the number of replicates. Data given in results represent the averaged response of 3 - 5 seedlings.

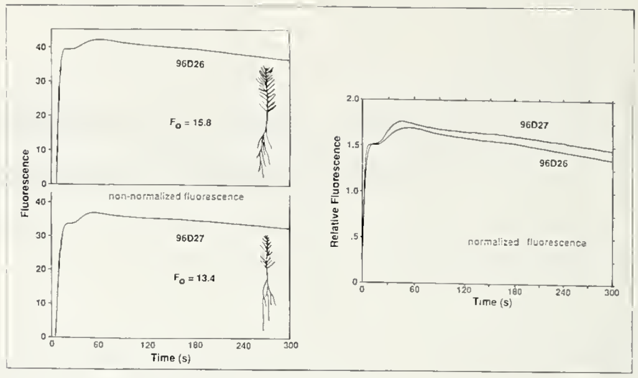

Figure 3.--The normalization operation largely compensates for differences in amplitude of individual White spruce seedling Fv curves. Non-normalized F_{ϑ} curves (left) of seedling 96D26 and 96D27 are from the same seedlot (8981).Their normalized Fv transients are compared in the right.

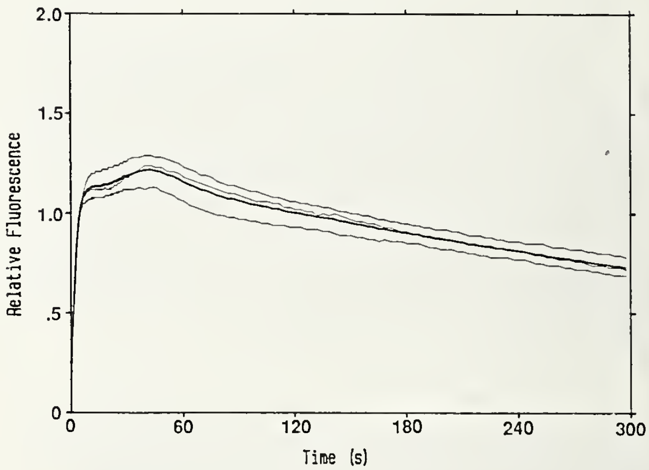

Figure 4.--Normalized Fv responses of individual White spruce seedlings (seedlot 8981) are shown as fine lines. The averaged Fv response of the three seedlings is shown as the broad line.

RESULTS

Photochemical Inactivation

Fv curves shown in Fig. 5 show a sequential decline in Fv amplitude for 1-0 White spruce container-grown stock. This decrease in fluorescence is accompanied by reductions in the rate of apparent photosynthesis (APS). The fluorescence decline represents a decrease in the rate of the primary photosynthetic process of water splitting (Toivonen and Vidaver, 1988), thus reducing the potential for photodamage in high ambient light under cold temperatures (Peeler and Naylor, 1988) when biochemical CO_2 assimilation is inhibited. Inactivation of photosynthetic activity (shutdown) is considered by us to be an indicator of the winter hardening-off process.

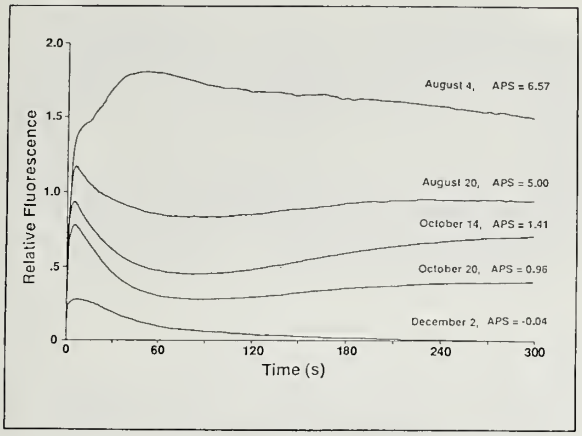

Figure 5.--Sequential inactivation of photosynthetic activity in White spruce seedlings (8981). The Fv decline with the approach of Fall reflects the inactivation of photochemical water splitting (shutdown). The decline in Fv appears to be mainly daylength dependent. These seedlings experienced no frost during the inactivation period. APS is expressed as mg CO_2 g dry wt^{-1} h^{-1}.

From this series of curves, we suggest that these seedlings could have been lifted for cold dark storage by Oct. 20. The -18 C cold hardiness tests (British Columbia Ministry of Forests (BCMOF)), (Simpson, 1985) performed immediately after Fv established that the seedlings had also achieved cold-hardiness at that time. The barely positive APS rates determined at 25^{o} C would have been negative at ambient temperatures. The nursery operational lifting date was Dec. 2 for the same stock.

Provenance Differences in Shutdown Time

Differences were detected using Fv in the level of photochemical inactivation in two provenances of White spruce. In Fig. 6, the upper curve shows that more southern provenance seedlings (seedlot #8534, ca. 54^{o} 50'N, Fort St. James, B.C.) had not reached the same level of inactivation by Nov. 17 as the northern provenance (#8981, ca. 57^{o} 50' N, Fort Nelson, B.C.). The earlier progression toward shutdown in the northern provenance may indicate an adaptation to the earlier onset of winter conditions which would be experienced by these seedlings.

Recovery From Cold Dark Storage

Root growth capacity (RGC) assessment of seedling vigor following removal from cold dark storage usually takes one to three weeks (Burdett, 1979). Seedlings in which Fv had returned to near pre-shutdown levels within 48 h after removal from storage (Fig. 7, Table 1) also had high RGC scores. Seedlings exhibiting little recovery of Fv after 48 h had poor RGC's (Table 1).

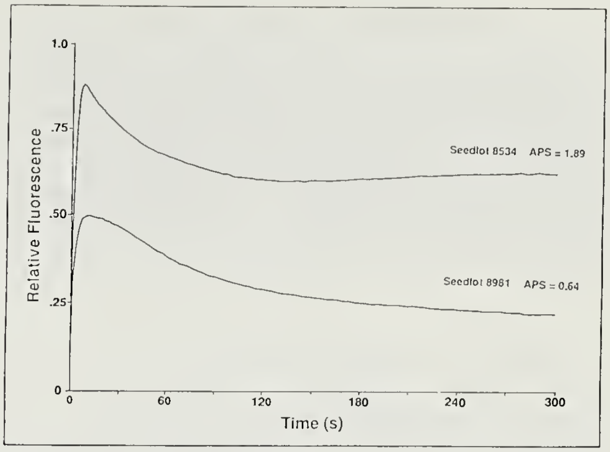

Figure 6.-- Provenance differences in the photosynthetic inactivation of White spruce seedlings. Other data as in Fig. 5.

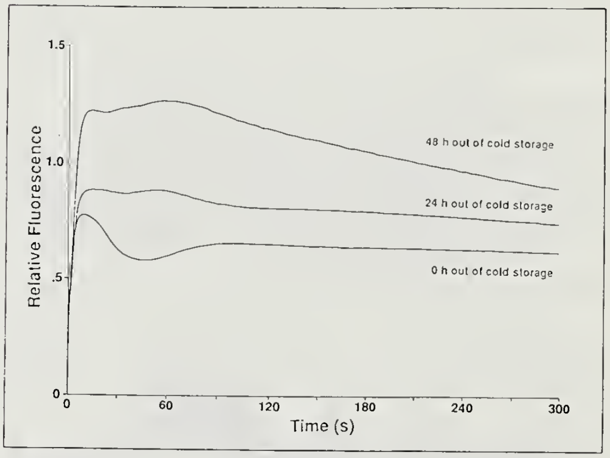

Figure 7.--Recovery of Fv on removal from cold dark storage in White spruce seedlings (seedlot 4073). On removal from storage the seedlings were repotted, watered and equilibrated to room temperature. Note that within 48 h, Fv had largely recovered to levels expected from fully active seedlings (top curve in Fig. 5).

Table 1.-- Maximum Fv values 48 h following removal from cold dark storage and corresponding RGC scores for White spruce seedlings. (Values are means ± standard errors.)

Seedlot	n =	Fv(max)	RGC
4073	5	1.28 ± 0.16	4.88 ± 0.15
8503	6	0.37 ± 0.40	0.62 ± 0.5
8782	6	0.53 ± 0.01	1.06 ± 0.44
8533	6	0.63 ± 0.2	1.13 ± 0.02

This correlation is consistent with the findings of Van den Driessche (1987) which indicated that new root growth is dependent on current photosynthetic activity.

Natural Water Stress and Recovery

From June 1 to July 15, 1987 there were large ambient temperature and relative humidity fluctuations at the growing sites (Fig. 8). This resulted in increased water stress in White spruce (seedlot #8534) seedlings on a 48 h watering cycle as indicated by both fluorescence and CO_2 exchange data (Fig. 9). When temperatures markedly declined at the beginning of July, both CO_2 exchange and Fv recovered.

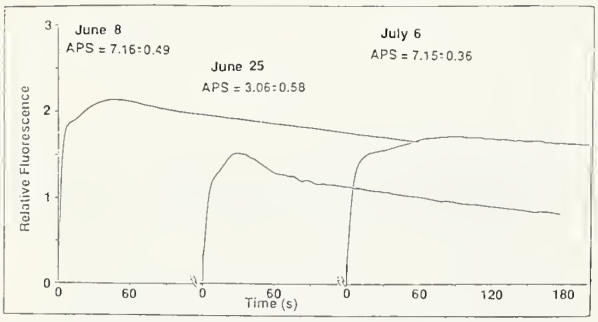

Figure 8.--Changes in Fv and APS of white spruce seedlings (seedlot 8534) under water stress occurring during the second year of the production cycle. Both June 8 and July 6 represent periods of cooler temperatures and therefore lower water stress potential. APS (mean ± standard error) given as CO_2 g dry wt^{-1} h^{-1}.

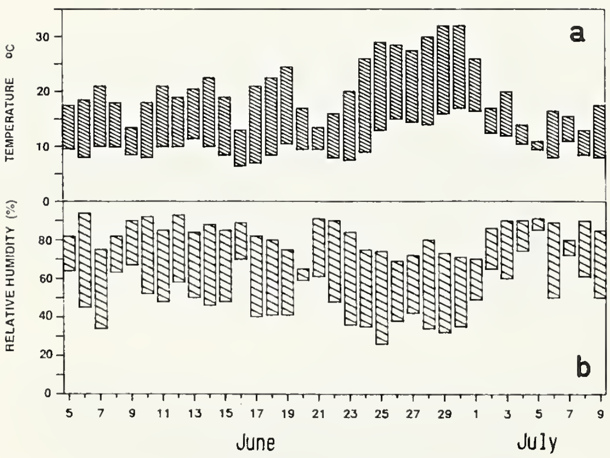

Figure 9.--Temperature range and humidity range data for the period June 5 to July 9, 1987 from a weather station at SFU. Fv and APS measurements were done on June 8 and 25, and on July 6, 1987.

Induced Water Stress and Recovery

Withholding water for various intervals induced symptoms of water stress in 2-0 seedlings of seedlot 8981. On rewatering, recovery (see Figs. 10 -11) depended on the fluctuations in temperature and humidity (Fig 12).

Seedlings last watered on July 14 exhibited mild water stress on July 16 (Fig. 10). Following watering (immediately after Fv assessment on July 16), the seedlings showed some recovery over the next day. High evaporative demand during July 17 (Fig. 12) resulted in marked water stress as indicated by reduced Fv on July 18 (Fig. 11). Following rewatering on July 18, together with lower temperatures, higher relative humidities and therefore lower evaporative demand, the seedlings recovered overnight as indicated by the July 19 Fv curve.

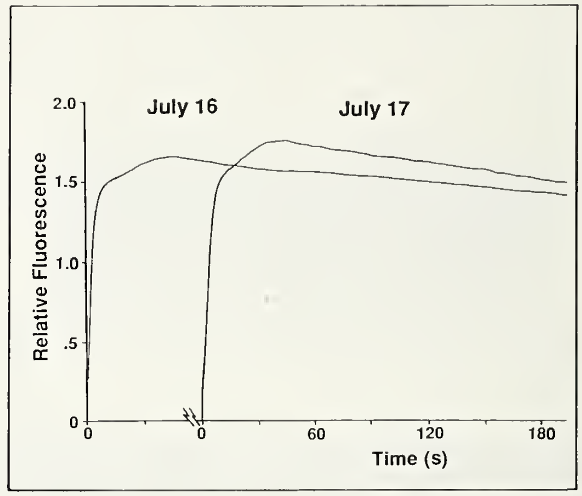

Figure 10.--Response of white spruce (Seedlot 8981) to 48 hours without water on July 16 and the recovery 18 hours after rewatering on July 17. This period of time was characterized as having a low evaporative potential.

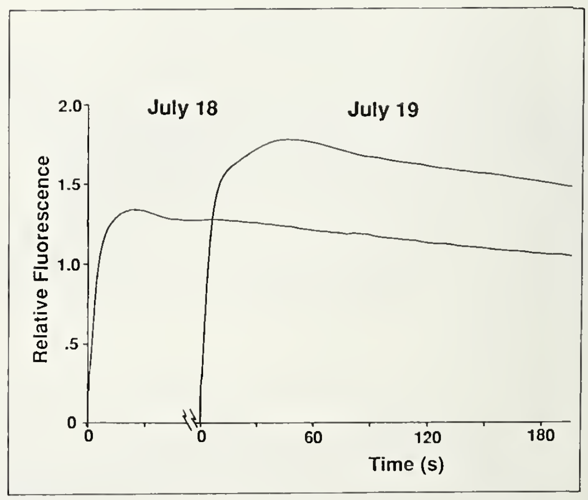

Figure 11.--Response of white spruce (seedlot 8981) to 48 hours without watering on July 18 and the recovery 18 hours after rewatering on July 19. The day prior to July 18 had relatively high evaporative potential.

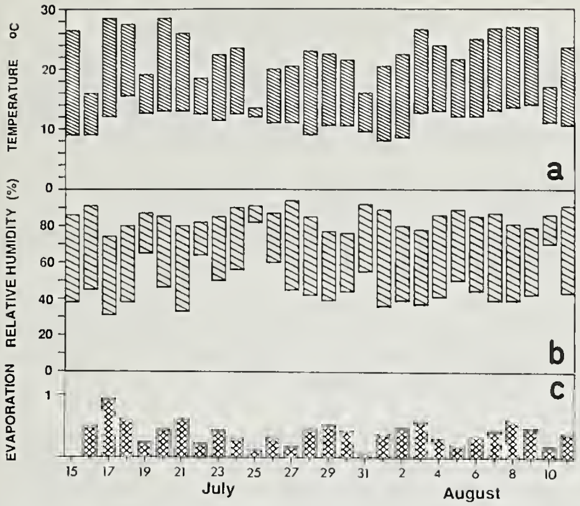

Figure 12.--Temperature range, humidity range, and relative evaporation data for the period of July 15 to August 10, 1987 from a weather station at SFU. Evaporation was measured with a Piche evaporimeter and the units are relative.

Phosphorus Nutrition

In this trial, phosphorus was applied as 20-20-20 (Green Valley) at varying frequencies during the growing season to 1-0 Douglas-fir seedlings. The frequency of P application was: every 2 wks, 4 wks, 6 wks or no application at all. All other nutrients were applied at regular 2 week cycles. The shape of the Douglas-fir Fv induction curve can be seen to be different from that of White spruce (Fig. 13). This difference is likely due to higher water-splitting activity in Douglas-fir compared to White spruce. The difference appears to be reflected in higher Douglas-fir APS rate (Fig. 13) which is typical for the

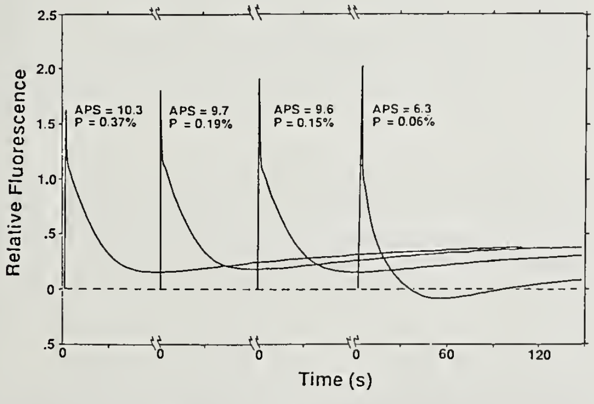

Figure 13.--Changes in Fv, APS, and phosphorus content of Douglas-fir (seedlot 1293) when P was applied (from left to right) every 2 weeks, 4 weeks, 6 weeks, or not at all during the growing season of 1987. APS units are mg CO_2 g dry wt^{-1} h^{-1}, phosphorus (P) content as % total dry weight .

seedling during the growing season. An initial effect of lowering P was observed with the treatment resulting in 0.19% P content; the initial Fv transient was slightly higher than for the control treatment while APS did not decrease significantly. At the lowest P level (right-hand curve), the initial Fv transient was still higher and APS decreased to 60% of the initial value, and the decline from the initial peak was faster. The effect of these P levels on photochemical water splitting could be associated with some decrease in the activity of the dark reactions of CO_2 assimilation.

DISCUSSION

Data from Fv assessment provides information about the physiological status of conifer seedlings during the nursery production cycle.

In White spruce seedlings inactivation of photochemical water splitting (shutdown) occurs primarily in response to daylength. The onset of shutdown appears to be influenced by the latitude of seedlot provenance; shutdown occurs earlier in the fall in the northern than the more southern provenance. As shutdown is presumably related to the winter-hardening process and may be indicative of the extent of hardening, Fv assessment provides information of potential advantage in the selection of pre-storage lifting dates. Any delay in lifting could result in seedlings being lifted well after the optimal date and unnecessary losses in seedling nutrient reserves could occur. Fv assessment indicates physiological reactivation in the event of a warming trend after the chilling requirement has been filled (see the bottom curve in Fig. 5. and the top curve in Fig. 7). Reactivated seedlings would likely undergo nutrient losses and possibly physical damage while in cold dark storage.

The use of Fv to assess recovery from cold dark storage by monitoring the reactivation of photochemical water splitting could provide a good indication of seedling quality. Recovery of Fv appears to be related to root function. In experiments not shown here (Vidaver, *et al.* 1988), it was observed that watered and repotted seedlings showing little or no recovery, recovered more rapidly and to a greater extent when shoots were detached and the stem was placed directly in water.

Symptoms of water stress observed with Fv assessment during periods of high evaporative demand could likewise be indicative of the failure of the seedling root system to provide sufficent shoot moisture. Episodes of partial inactivation due to water stress may result in seedling set back or failure to reach BCMOF morphological growth standards during the growing season. Operational application of Fv could alert growers to the need for more effective watering regimes or the production of more efficient root systems.

The data from the P experiments suggest that potential utilization of nutrient stress to regulate morphological development could be monitored by Fv. In withholding P, APS was suppressed which if sustained would obviously restrict seedling growth. In these experiments restoring P, rapidly resulted in the full recovery of Fv (data not shown).

SUMMARY

These preliminary results of the application of Fv assessment to the physiological status of conifer seedlings suggests that operational application of the fluorometer system to seedling production could provide substantial benefits to the nursery industry.

1] Fv measurement can provide a simple, rapid, reliable and non-destructive method of evaluating seedling physiological status during the nursery production cycle.

2] Fv measurement provides information which can be used in determining lifting dates, the effects of water stress and nutrient regimes, and for assessing post-storage vigor.

ACKNOWLEDGEMENTS

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245 # Effect of the Timing of Cold Storage on Cold Hardiness and Root Growth Potential of Douglas-fir[1]

Karen E. Burr and Richard W. Tinus[2]

Abstract.--Container-grown Douglas-fir seedlings were cold acclimated in growth chambers over 20 weeks. At weekly intervals, cold hardiness and root growth potential (RGP) were measured, and additional seedlings were placed in 1°C storage for 4 weeks. Cold hardiness and RGP were reassessed following storage. Cold hardening continued in storage regardless of when during acclimation seedlings were stored. However, the rate of cold acclimation increased or decreased during storage depending on the level of cold hardiness at the start of the storage period. RGP generally declined during storage, though occasionally remained the same or increased without apparent relation to level of cold hardiness.

INTRODUCTION

The recent focus of tree seedling quality research has been on seedling attributes that indicate physiological condition and stress resistance, with the recognition that both morphological and physiological measures of quality are necessary (Duryea 1985, Ritchie 1984, Sutton 1979). Such physiological attributes include cold hardiness, root growth potential (RGP), and bud dormancy. There is much to be gained by understanding the interrelationships of these attributes, not only as it contributes to basic science through defining the annual physiological cycle of nursery-grown seedlings, but also from a practical perspective. Quickly measured information on cold hardiness could be used as a rapid estimator of RGP and bud dormancy, attributes more time consuming to measure, if a consistent relationship between the three could be established.

Toward this end, the U.S. Forest Service Rocky Mountain Forest and Range Experiment Station stress physiology project at Flagstaff, Arizona has been examining the interrelationships between cold hardiness, RGP, and bud dormancy in southwestern conifers. The initial approach was to simulate that portion of the annual cycle from bud set to bud break under controlled growth chamber conditions, and to measure all three attributes concurrently at frequent intervals (Tinus et al. 1986). In this way, relationships between the attributes were established. However, these relationships were observed only under a single set of temperature and photoperiod conditions. Recently completed experiments examined the cold acclimation and deacclimation of interior Douglas-fir and the associated changes in RGP and bud dormancy using several different sets of temperature conditions. Additionally, the effects of transferring seedlings to optimum growing conditions or to cold storage at intervals throughout acclimation and deacclimation were measured. This paper presents the results from one of those cold acclimation regimes and the effects on cold hardiness and RGP when seedlings were transferred to cold storage at intervals throughout acclimation.

MATERIALS AND METHODS

Seedlings of interior Douglas-fir (Pseudotsuga menziesii var. glauca) of the same seed source as in our previous experiments (Tinus et al. 1986) were greenhouse-grown in 240-ml Rootrainer[3] book containers in a peat-vermiculite mix for 8.5 months (Mar. 17 - Dec. 1, 1987). Greenhouse temperatures averaged 25°C daily and 22°C at night. Daylength was extended to 22 hours

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[2]Karen E. Burr is Research Plant Physiologist and Richard W. Tinus is Principal Plant Physiologist, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.

[3]Trade names are used for brevity and specificity, and do not imply endorsement by the USDA to the exclusion of other equally suitable products.

with fluorescent light (7.5 umol s^{-1} m^{-2}). Watering was as needed, with a high-nitrogen complete nutrient solution (223 ppm N, 36 ppm P, 151 ppm K). Other cultural conditions were as recommended by Tinus and McDonald (1979). Actively growing seedlings were then placed in Percival HL-60 growth chambers for a 2-stage, 20-week cold acclimation regime. Day/night temperatures were 20°/15°C during the first 4-week stage, and 10°/3°C during the second 16-week stage. Daylength was 10 hours throughout the 20 weeks (518 umol s^{-1} m^{-2}). Watering was as needed, with a low-nitrogen complete nutrient solution (20 ppm N, 86 ppm P, 151 ppm K).

A random sample of 24 seedlings was taken from the growth chamber population at weekly intervals. Needle tissue was removed from each seedling for a freeze-induced electrolyte leakage (FIEL) test of cold hardiness. The seedlings were then randomly divided into two equal groups, with one group used in an aeroponic RGP test, and the other placed in 1°C storage for 4 weeks. Cold hardiness of the stored seedlings was measured with the FIEL test weekly, or after 1, 2, and 4 weeks, during the 4-week storage period. RGP of the stored seedlings was measured at the end of the storage period.

Cold Hardiness Test

The FIEL test procedures to measure needle tissue cold hardiness were similar to those previously described (Burr et al. 1986). Needles were removed from the second to the last flush along the central axis of each seedling in the sample to be tested. An equal number of needle segments, 1 cm long, cut at both ends, were prepared from each seedling. Segments were pooled into four equal groups such that the trees represented by each group were the same every time testing was conducted. The segments were washed in distilled water and transferred to culture tubes containing 0.5 ml distilled water. Each group of segments was used to fill six tubes, six needles per tube.

The 24 tubes were then divided into sets of 4 such that each set included 1 tube from each of the 4 groups of segments. In this way, four groups of seedlings within each sample were independently monitored. One set of tubes was stoppered and placed in a refrigerated water bath at 1°C as a control. The other 5 sets of treatment tubes were placed in a Forma Scientific ethanol bath at -2°C. After 0.5 hour, the water in the treatment tubes was nucleated and the tubes were stoppered. The ethanol bath was then cooled at the rate of 5°C per hour.

At each of 5 test temperatures, selected to span 20 to 80% injury, 1 set of treatment tubes was removed to thaw in the 1°C water bath. After all tubes were removed from the ethanol bath and thawed, 5.5 ml of distilled water were added to each of the 24 tubes, and all were stoppered and placed in a 100-rpm shaker at 24°C for 20 hours incubation. Conductivity of the solution in each tube was measured after incubation with a YSI conductance meter and microcell, and the tubes were then placed in a boiling water bath for 15 minutes to induce complete tissue injury. Conductivity was remeasured after an additional 20 hours incubation in the shaker.

Test results, which were available in 2 days, were measured as percent index of injury according to Flint et al. (1967). A modified Gauss sigmoid model (Grosenbaugh 1965) was fitted to each data set, and the temperature at 50% index of injury (LT50) was estimated by inverting each model.

Root Growth Potential (RGP) Test

RGP was measured using an aeroponic system similar to that described by Burr et al. (1987). The mist chamber measured 1.0 m wide x 2.4 m long x 0.6 m high, was constructed of 5-cm-thick rigid urethane foam, and was fitted with a copper tubing, 3-nozzle mist system 25 cm above the floor of the chamber. Conditions within the chamber were maintained at 100% relative humidity and 27°C by a warm-water intermittent mist and a 10-cm layer of vermiculite in the bottom of the chamber. Rootballs, with potting mix intact, were suspended within the chamber using foam-lined redwood seedling clamps which formed the top of the chamber. RGP tests were conducted in a greenhouse with day/night temperatures averaging 21°/18°C and a 22-hour photoperiod extended with fluorescent light (7.5 umol s^{-1} m^{-2}).

RGP was quantified as the total number of new roots per seedling ≧0.5 cm in length after 14 days in the mist chamber. Means and standard errors were calculated for each sample of 12 seedlings.

Storage Treatment

The 1°C storage treatment was maintained in a 1.5 m x 0.7 m x 1.3 m cooler. Stored seedlings were kept in darkness except when removed from the cooler for weekly sampling of tissue for the FIEL test and for watering, which was as needed with the low-nitrogen nutrient solution. Seedlings, in the book containers, were placed upright in the cooler without wrapping or packaging.

RESULTS

Cold Hardiness

Douglas-fir cold hardiness increased from -5°C to -32°C during the 2-stage, 20-week growth chamber cold acclimation regime that excluded exposure to freezing temperatures (fig. 1). Cold acclimation proceeded slowly during the first 4-week stage when day/night temperatures were 20°/15°C. When day/night temperatures were lowered to 10°/3°C in the second stage, cold acclimation proceeded rapidly, reaching a maximum rate of approximately 1°C per day during the ninth week. Maximum cold hardiness, under these conditions, was reached in 14 weeks. No further cold acclimation occurred between week 14 and week

20, though cold hardiness may have oscillated somewhat. Cold hardiness as a function of time was highly predictable under these conditions. The LT50's for the entire 20-week period were regressed using a weighted least squares non-linear regression assigning higher weight to early weeks (R^2= .983).

Cold acclimation continued during the 4-week, 1°C storage period regardless of when seedlings were stored during the 20-week acclimation regime (fig. 2). This change in seedling environment, from growth chamber to storage conditions, was accompanied by an increase or decrease in the rate of cold acclimation, depending on the level of cold hardiness at the start of the storage period. Seedlings stored in weeks 0 through 2, with cold hardiness between -5° and -6°C, acclimated more rapidly in storage than seedlings remaining under growth chamber conditions. Seedlings stored in weeks 3 through 10, which included the period of most rapid cold acclimation in the growth chambers, acclimated more slowly in storage than seedlings remaining under growth chamber

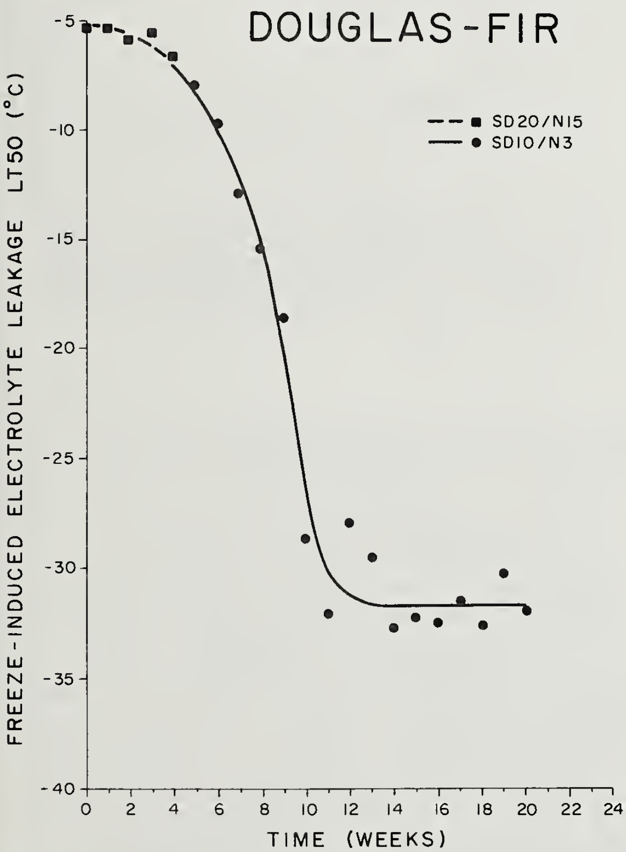

Figure 1.--Temperatures resulting in 50% index of injury to needle tissue in the FIEL test (LT50), as a function of time under growth chamber conditions. R^2= .983
$LT50 = -31.83 + 26.27e \exp(-0.000031W^{4.706})$
where W= week.
Dashed line = short day 20°C, night 15°C.
Solid line = short day 10°C, night 3°C.

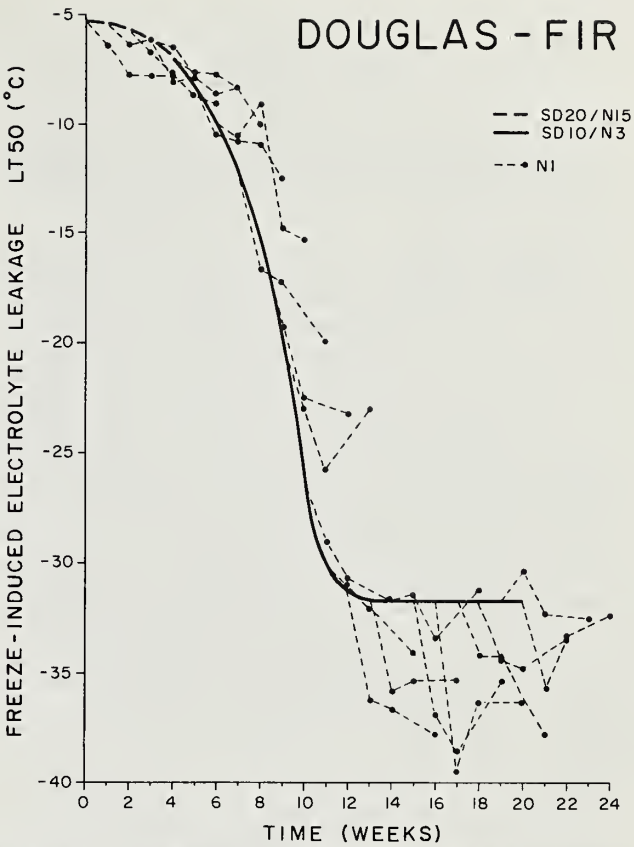

Figure 2.--Regression of 50% injury temperatures from figure 1, with temperatures resulting in 50% index of injury to needle tissue when seedlings were transferred at weekly intervals to 1°C storage (N1) for 4 weeks.

conditions. Seedlings stored in weeks 11 through 20 continued to cold acclimate appreciably in storage, while seedlings remaining under growth chamber conditions reached maximum cold hardiness and stopped acclimating.

Root Growth-Potential (RGP)

Douglas-fir RGP, measured as total number of new roots per seedling at 14 days, increased from 55 to 145 during the 20-week growth chamber cold acclimation regime (fig. 3). The initial rapid rise in RGP from 55 to 125 new roots per seedling coincided with the period of rapid cold hardening during the first 12 weeks. When seedling cold hardiness was at or near maximum under the growth chamber conditions, weeks 12 through 20, RGP remained high but fluctuated widely.

RGP generally declined during the 4-week, 1°C storage period, though occasionally remained the same or increased without apparent relation to the level of cold hardiness at the start of the storage period (fig. 4). However, RGP after 4 weeks storage increased from 25 new roots per seedling placed in storage week 0 to almost 130 new roots per seedling placed in storage week 20.

DISCUSSION

Cold Hardiness

The pattern of cold acclimation (fig. 1) was similar to that measured in the previous growth chamber experiment with this seed source (Burr et al. 1986, Tinus et al. 1986). However, the maximum rate of cold acclimation was twice as fast as previously measured. Seedlings in the current experiment reached an LT50 7°C lower than seedlings in the previous experiment did in the same length of time. Changes in greenhouse cultural conditions during seedling production to prevent bud set and promote active growth until the start of the current experiment, such as a reduction in moisture stress through more frequent watering, may have predisposed the current crop of seedlings to cold acclimate faster. Timmis and Tanaka (1976) observed that severe moisture stress under long days reduced the rate of Douglas-fir cold acclimation, while mild stress under long days enhanced cold acclimation when both treatments were followed by short days at low temperatures. Cold hardening to -20°C without exposure to freezing temperatures has been previously observed in other conifers (Glerum 1973, Cannell and Sheppard 1982) but hardening to -30°C and below

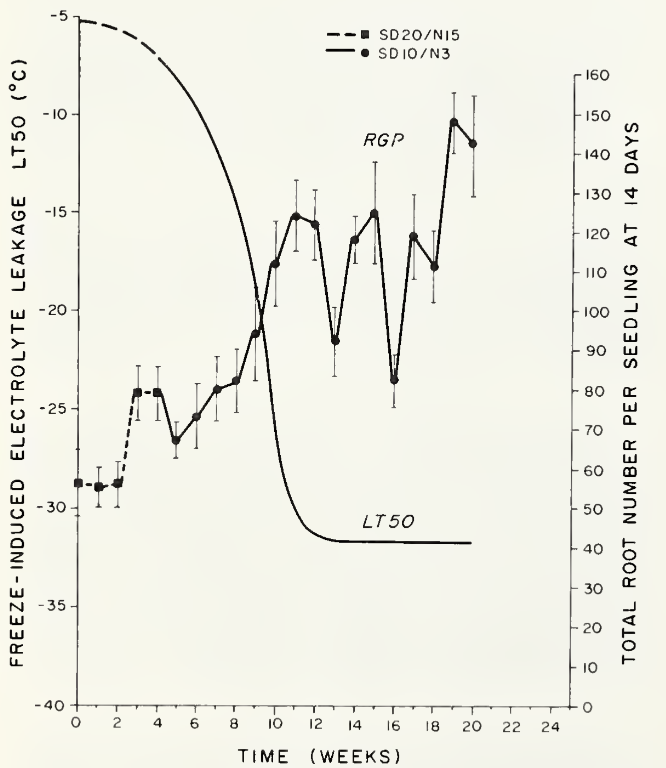

Figure 3.--Total number of new roots per seedling at 14 days (RGP) as a function of time under growth chamber conditions, with regression of 50% injury temperatures from figure 1 (LT50). Vertical bars are ±1 standard error. Standard errors ranged from 5 to 15, with a median of 8.

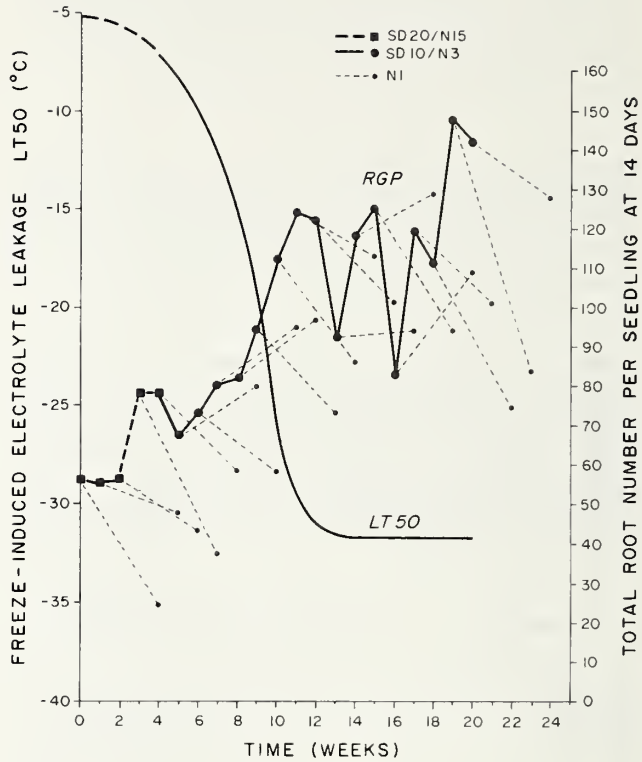

Figure 4.--Total number of new roots per seedling at 14 days (RGP) before (as in fig. 3) and after transfer at weekly intervals to 1°C storage (N1) for 4 weeks, with regression of 50% injury temperatures from figure 1 (LT50).

was of interest, especially since this FIEL tissue test was found to be approximately 10°C more conservative than a whole-plant freeze test LT50 estimate in this hardiness range (Burr et al. 1986).

The continuation of cold hardening in storage, regardless of when during acclimation seedlings were stored, and the restarting of the hardening process in storage after cold hardiness had stabilized under growth chamber conditions, suggest the importance of temperature, in the absence of photoperiod, for regulation of seedling physiology (fig. 2). Changes in the rate of cold acclimation were not random, but occurred in a readily identifiable pattern when seedlings were transferred from the growth chamber conditions into storage. It is anticipated that the extension of this pattern of rate changes over longer storage periods will result in a stabilizing of seedling cold hardiness throughout a wide range of LT50's such that the greater the level of cold hardiness at the start of storage, the lower the final LT50 attained. The lowest attainable LT50 for a sample of seedlings stored at any point along the acclimation curve would then be a function of genotype, production history, acclimation history, and storage conditions.

This seed source may or may not respond similarly to other handling and storage conditions. It should be noted that the container seedlings in this experiment were stored upright, with undisturbed root systems, good air circulation, and regular watering. Thus, many of the stresses associated with standard lifting, packaging, and storing procedures were minimized. This may have been critically important for the continuation of the cold hardening process in storage. Faulconer (1989) reported bareroot coastal Douglas-fir seedlings, lifted and packaged using operational procedures, deacclimated in storage unless stored when cold hardy to at least -15°C. A comparison of the two studies suggests that the stresses associated with the lift and pack process may disrupt physiological mechanisms permiting continued cold hardening in storage (Faulconer 1988).

Root Growth Potential

The RGP pattern (fig. 3) was similar to that previously measured for this seed source under cold acclimating growth chamber conditions (Tinus et al. 1986). RGP of the seedlings in both experiments was low when cold hardiness was minimum, increased rapidly during the period of rapid cold acclimation, and remained high but fluctuating when cold hardiness was maximum. The resolution of the pattern has been improved in the current experiment by more frequent measurement and the use of larger sample sizes. There are many reports of conifer seedling RGP increasing under natural conditions during the cold acclimation period (DeWald and Feret 1987, Jenkinson 1980, Ritchie and Dunlap 1980) and the pattern presented here was comparable. The relationship between the rapid increase in cold hardiness and the rapid rise in RGP, consistent in both this and the previous experiment, further supported the hypothesis that such relationships exist.

Storage was generally detrimental to seedling RGP throughout the cold acclimation period (fig. 4). There was no indication of an increase in seedling capacity to maintain RGP in storage as cold acclimation progressed. There are, however, many reports that early-lifted bareroot seedlings store poorly, losing RGP in storage, while fully hardy seedlings store without loss of RGP, and often with increased RGP, under storage temperatures and durations similar to those used in this experiment (DeWald and Feret 1988, Ritchie and Dunlap 1980). An explanation for this difference is not readily available. Until it becomes possible to identify and monitor the physiological changes occurring during storage that are manifested as a change in RGP, it will remain difficult to explain why RGP increases, decreases, or remains unchanged during any given period of time.

Though there was a general decline in RGP during storage throughout the acclimation period, RGP levels following storage increased with time as cold hardiness at the onset of storage increased. Seedlings stored after cold acclimating to at least -15° to -20°C maintained RGP levels during the 4-week storage period at least as high as unstored seedlings at the start of the acclimation period. Thus it was still possible to increase RGP over the initial level of 55 new roots per seedling, with a 4-week storage period, by placing seedlings in storage after a moderate level of cold hardiness was attained.

In summary, this was the second experiment in which Douglas-fir seedlings of a single seed source were cold acclimated in growth chambers at the U.S. Forest Service Flagstaff facility. The patterns of cold acclimation and RGP, as well as the relationship between the two patterns, were consistent in both experiments. At weekly intervals throughout the acclimation period, seedlings were placed in 1°C storage for 4 weeks. Cold acclimation continued in storage, though the rate of acclimation was altered in a predictable manner. RGP generally declined in storage, though RGP levels after storage increased with greater cold hardiness at the onset of storage. Effects of longer storage periods on cold hardiness and RGP remain to be determined.

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245

Basamid and Solar Heating Effective for Control of Plant-Parasitic Nematodes at Bessey Nursery, Nebraska[1]

Diane M. Hildebrand[2] and Gary B. Dinkel[3]

Abstract.--Methyl bromide/chloropicrin, Basamid®, and solar heating were compared for control of Fusarium spp., plant-parasitic nematodes and weeds at Bessey Nursery, Halsey Nebraska. All treatments controlled nematodes. Solar heating and polyethylene-sealed Basamid were less effective than methyl bromide for control of Fusarium spp. Water-sealed Basamid did not control Fusarium spp. Only methyl bromide and solar heating controlled weeds. A windstorm after treatment may have confounded results.

INTRODUCTION

In order to control damping-off fungi and other soil-borne fungal pathogens, plant-parasitic nematodes, and weeds, pre-plant fumigation with methyl bromide/chloropicrin is used on a regular basis at most Federal tree nurseries (Ruehle, 1986). Due to health hazards, alternative chemicals and cultural practices are continually being tested. In summer, 1985, the Manager at Bessey Nursery (Halsey, Nebraska) requested an evaluation of Basamid® as an alternative chemical fumigant, especially for control of plant-parasitic nematodes.

Basamid® (dazomet) reacts with moist soil to form methyl isothiocyanate, a degradable biocide. The fumigant vapors are kept in the soil by surface compaction and sealing with water. Polyethylene sheeting may be required for the sandy soil at Bessey. Basamid has been reported as effective in controlling weeds, nematodes, and soil-borne fungal pathogens (Neumann et al., 1984; Hopkins Co.).

An alternative to chemical fumigation is soil solar heating. Solar heating of soil is accomplished by covering moist soil with clear polyethylene sheeting for several weeks during midsummer. Solar heating has reduced populations of weeds and soil-borne fungal pathogens in forest tree nurseries (Cooley 1985; Hildebrand 1987). A previous study of solar heating effects on nematode populations at Bessey resulted in no observable treatment effect because of very low and highly variable population levels of plant-parasitic nematodes (Hildebrand 1985). Positive effects on tree seedling survival have not yet been demonstrated in forest nurseries, but a fall-sown crop would be the most likely to show benefit.

The objective of this evaluation was to compare soil treatments with methyl bromide/chloropicrin (Dowfume® MC-33), Basamid® Granular, and solar heating for effectiveness in reducing populations of species of Pythium, Fusarium, plant-parasitic nematodes, and weeds. Comparisons were planned also for effects on growth and survival of fall-sown eastern redcedar (Juniperus virginiana L.).

MATERIALS AND METHODS

Soil treatments for fall-sown eastern redcedar were begun in summer 1986 at Bessey Nursery. The portion of the nursery unit chosen for this evaluation showed nematode damage in the eastern redcedar crop lifted in spring 1986. The limited area with high nematode concentrations and the need to prevent cross-contamination between treatments necessitated limited replication.

Five treatments were replicated in two plots of 10 x 40 ft arranged as in figure 1. At the time of sowing, the tractor formed and sowed beds first in the methyl bromide/chloropicrin plots, then the polyethylene-covered Basamid plots, then the water-sealed Basamid plots, then the solar-heated plots, and finally the check plots. This sequence helped minimize contamination of the treated beds during sowing because the intensity of the biocidal effects of the treatments were expected to follow the same order. This plot layout helped ensure the presence of sufficient nematodes in all treatments. The nursery bed area adjacent to the treatment area was

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	|<------------------------	160-ft	------------------->|		
	|<--------	Eastern redcedar windbreak	-------->|		
	S	S	C	C	M
North Edge	WB	WB	PB	PB	M
	M*	M*	M	M	M

Figure 1.--Treatment plot layout: S = Solar-heated, C = Check, WB = Water-sealed Basamid, PB = Polyethylene-sealed Basamid, M = Methyl bromide/chloropicrin, M* = M plots for this study.

fumigated with methyl bromide/chloropicrin and the entire unit was sown to easter redcedar following normal nursery practices.

Treatments

1. (M) Fumigation with Dowfume® MC-33 (67% methyl bromide and 33% chloropicrin) at 350 lb per acre in late July, 1986. The chemical was injected into the soil and the soil surface sealed with polyethylene sheeting for 5 days and then the polyethylene was removed.

2. and 3. Basamid® Granular (Hopkins Co.) was spread evenly over the soil surface at 350 lb per acre and tilled into the top 8" in late July, 1986. The water-sealed (WB) plots were packed flat with a bed packer, and sealed by light irrigation. The water seal was repeated once to prevent surface cracking. The polyethylene-sealed (PB) plots were irrigated lightly and covered with 1.5 mil clear polyethylene sheeting for 10 days. After 10 days the four Basamid plots were cultivated to facilitate dispersal of fumigant vapors. Several oat seeds were sown in one check, one PB, and one WB plot 2 weeks after cultivation to test for residual toxicity.

4. (S) Solar-heated plots were watered to field capacity and covered with 1.5 mil clear polyethylene for 6 weeks beginning in early July, 1986. The polyethylene was removed immediately before sowing.

5. (C) No chemicals were applied to check plots. Check plots remained under the sudan grass cover crop until mid-July, 1986.

In order to maximize benefit from soil treatments, the sudan grass cover crop was plowed under about 2.5 weeks prior to each treatment. Beds were formed and eastern redcedar sown and mulched (covered with clear polyethylene and lathe board) three weeks after cultivation of the Basamid plots.

Sampling

Soil samples were taken a few days before treatment and a few days before sowing. One 6" core was taken with a soil bucket auger (3" diameter) for each sample, with 5 samples per treatment plot. The bucket was wiped clean of soil between samples.

A small portion of each sample was assayed for population levels of species of *Pythium* and *Fusarium* at the Rocky Mountain Region Forest Pest Management Lab. Standard assay procedures developed by Forest Service Plant Pathologists for the Reforestation Improvement Program (Landis 1986) were used except for the selective media. The selective medium for *Pythium* spp. was from Hendrix and Kuhlmann (1965) and for *Fusarium* spp. from Nash and Snyder (1962). The rest of the soil from each sample was shipped to Peninsu-Lab (Kingston, Washington) for assay for plant-parasitic nematodes.

Fungal populations were again assayed in mid-June, 1987. Plant-parasitic nematodes were again assayed by Peninsu-Lab in soil samples taken in late July, 1987. The number of weeds per 3 sq ft and the percentage of weed cover were determined in mid-May, 1987, in 6 sample areas per treatment plot. Weeds were then removed by hand in the treatment plots. The number of living, dying, and dead eastern redcedar seedlings were counted every 3 to 4 weeks in 6 sample areas per treatment plot beginning in mid-May, 1987. Dying seedlings were examined for causal agents and number of seedlings per square foot were determined. Final seedling counts were made in late July, 1987.

Temperatures

Soil temperature data for solar heated and check plots were taken during previous studies at Bessey Nursery (Hildebrand 1987), and were not gathered for this evaluation.

RESULTS

Two weeks after cultivation of the Basamid treatment plots, germination of oats indicated no residual toxicity, and sowing was completed on schedule. Because sample variances were quite heterogeneous, the test for equality of means with unequal variances was used for all comparisons (Sokal and Rohlf, 1981).

Fungi

Population levels of *Pythium* spp. were too low to show any treatment effects. Population levels of *Fusarium* spp. were significantly decreased only by the methyl bromide (M) and solar (S) treatments (figure 2). Methyl bromide treatment was more effective than solar heating in reducing population levels of *Fusarium*. In both Basamid (PB and WB) treatments, *Fusarium* populations were concentrated in pockets, while those in solar plots were more evenly distributed at low levels. Between pretreatment and post treatment samples, *Fusarium* levels in check plots increased significantly while those in each Basamid treatment remained statistically similar. By the following June, 1987, *Fusarium* levels increased (not significantly except in M plots) in all treatments, but levels in M, S, and PB treatments were significantly lower than in check and WB treatments. Population levels of *Fusarium* spp. greater than 1000 propagules per gram of oven-dried soil are expected to cause noticeable damping-off in susceptible species.

Nematodes

Population levels of plant-parasitic nematodes in the check and PB plots were significantly higher than in other plots before treatment. Population levels remained high in the check plots, while being significantly reduced by all other treatments (figure 3). The chemical treatments, M, PB, and WB, were equally effective, and somewhat more so than solar heating. The nematode levels remaining in the solar plots were below the threshhold for seedling damage (200 nemas per pint of field moist soil), based on previous sampling in healthy and diseased eastern redcedar at Bessey Nursery. By the following July, 1987, nematode levels were still at potentially damaging levels in check plots, while remaining low in all other treatments.

Weeds

In mid-May, 1987, the predominate dicotyledonous weed was mare's tail or horseweed, *Conyza canadensis* (L.) Cronq., while the predominate grassy weed was downy brome, *Bromus tectorum* L. The average number of weeds and percentage weed cover in the treatment plots are summarized in figure 4. Numbers of weeds were significantly reduced compared to checks only in methyl bromide and solar plots. Weed cover was significantly reduced only in solar plots. Weeds and weed cover in the Basamid plots were not significantly reduced compared to that in check plots.

Temperatures

Temperature data from a previous study at Bessey (Hildebrand 1987) is presented in figure 5. Highest temperatures averaged 8°C higher in solar than in check plots. Average high temperatures recorded at 30 cm depth were much lower than near

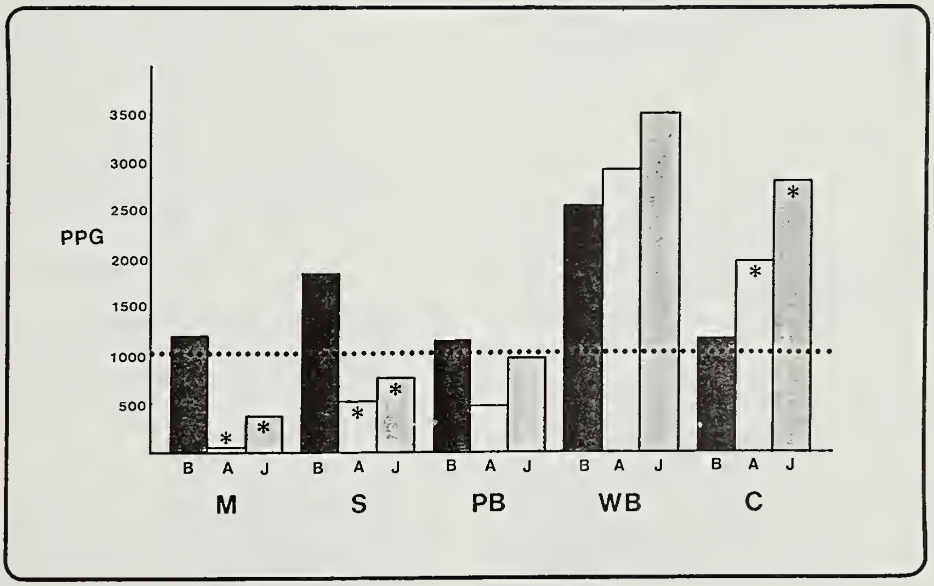

Figure 2.--Means and their significance for population levels of *Fusarium* spp. in propagules per gram of oven-dried soil (PPG) in methyl bromide/chloropicrin (M), polyethylene-sealed Basamid (PB), water-sealed Basamid (WB), solar-heated (S), and check (C) plots before (B) and after (A) treatment in summer 1986, and the following June (J) 1987 at Bessey Nursery. Asterisks indicate significant difference (P<0.05) from the before treatment mean.

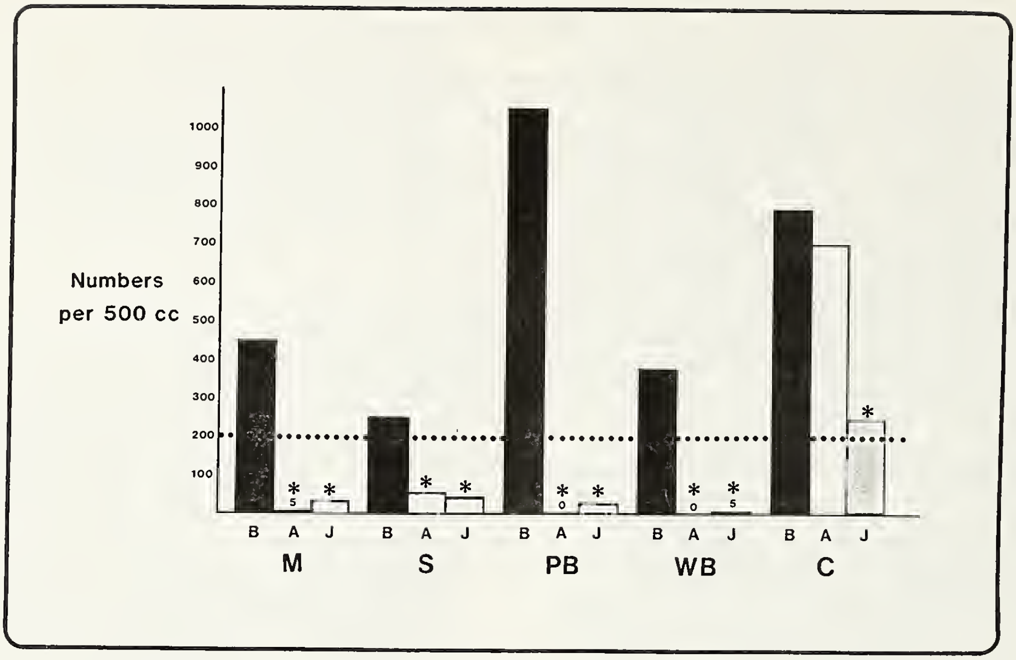

Figure 3.--Means and their significance for population levels of plant-parasitic nematodes (numbers per pint of soil) in methyl bromide/chloropicrin (M), polyethylene-sealed Basamid (PB), water-sealed Basamid (WB), solar-heated (S), and check (C) plots before (B) and after (A) treatment (summer 1986), and the following July (J) 1987 at Bessey Nursery. Asterisks indicate significantly different (P<0.05) from the before treatment levels.

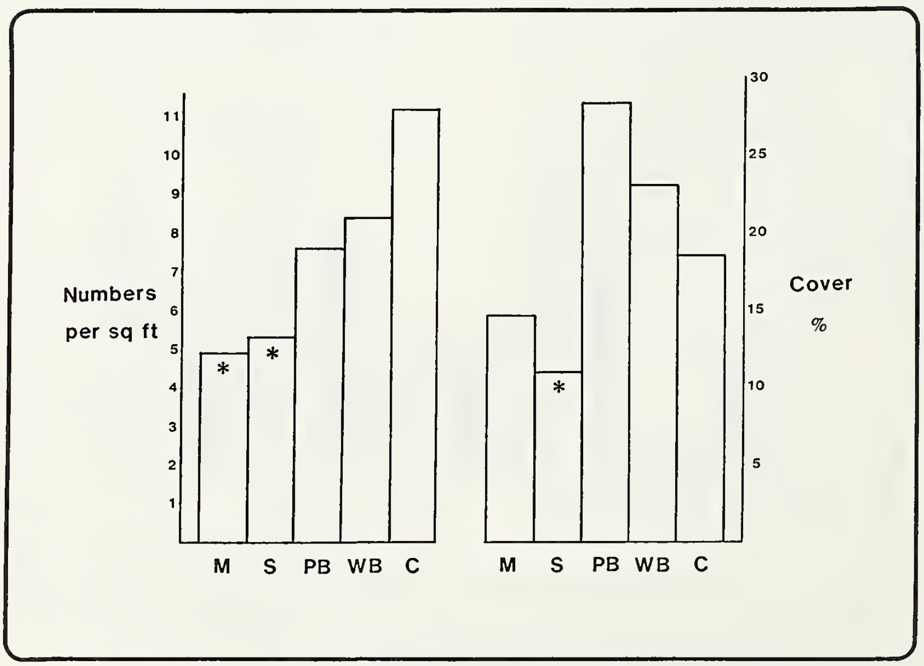

Figure 4.--Means and their significance for weed numbers (per sq ft) and weed cover in methyl bromide/chloropicrin (M), polyethylene-sealed Basamid (PB), water-sealed Basamid (WB), solar-heated (S), and check (C) plots in May 1987. Asterisks indicate significantly different from check.

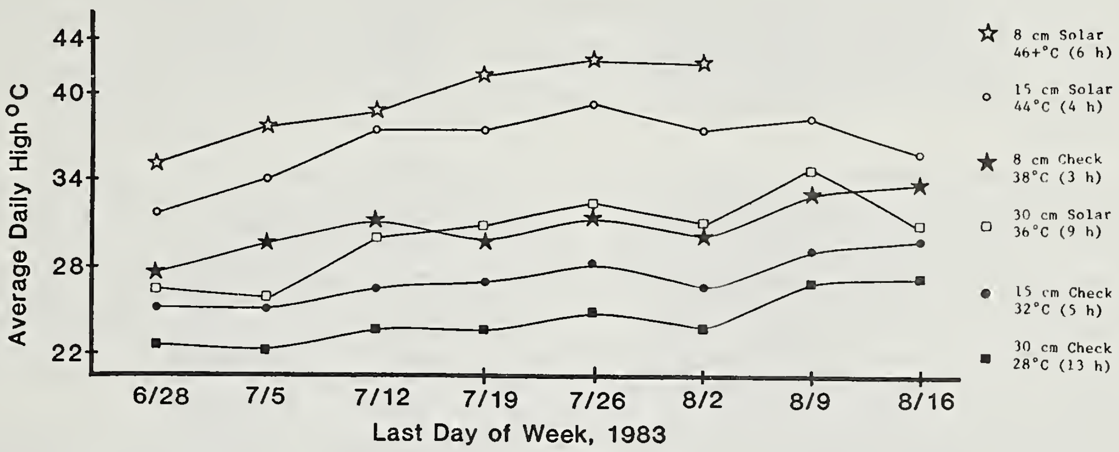

Figure 5.--Weekly averages of daily high temperatures recorded by thermographs buried at 8, 15, and 30 cm in one solar and one check plot at Bessey Nursery, 1983. Highest temperature achieved and the duration in hours (h) that the temperature remained within 1°C of the the high is given for each thermograph.

the surface (8 cm), but temperatures remained within 1°C of the daily highs much longer at greater depth. At 8 cm in the solar plot, 46°C (the limit of the recording capability of the thermograph used) was exceeded several times. At these times, the temperature remained above 45°C for 2 to 6 hours, averaging 4.1 hours. While the temperature was off-scale (46+°C) on August 2 at 8 cm in the solar plot, the recording chart tore and the subsequent record was lost.

Seedling Survival

Eastern redcedar seedlings succumb to damping-off caused by Fusarium spp., but only rarely (0.6% in this study). Seedling survival in May and July 1987 is presented in Table 1. Stocking in all treatments was far less than the standard

Table 1.--Average number of seedlings per square foot in treatment plots: methyl bromide/chloropicrin (M), polyethylene-sealed Basamid (PB), water-sealed Basamid (WB), solar-heated (S), and check (C), in May and July 1987 at Bessey Nursery.

	M	PB	WB	S	C
May	11.4	0.1	6.8	0.1	0.1
July	9.9	0.1	5.2	0.1	0.1

25 seedlings per square foot. So few seedlings survived frost damage early in the spring that those remaining were more susceptible to sun scorch and burial by blowing sand.

DISCUSSION

According to soil assays, Basamid was as effective as fumigation with methyl bromide/chloropicrin for controlling plant-parasitic nematodes. Solar heating was effective in reducing populations of plant-parasitic nematodes, but not quite as effective as chemical fumigation.

For reducing populations of Fusarium spp., methyl bromide fumigation was best, followed by solar heating and polyethylene-sealed Basamid. The heavy windstorm prior to sowing may have contributed many of the fungal propagules that increased the variability in population levels of Fusarium in post treatment samples. Vaartaja (1967) showed that fungal reinfestation of fumigated soil occurs by blowing dust. If the concentrated pockets of Fusarium in the Basamid plots were a result of Basamid treatment, use of Basamid would probably result in pockets of losses for most conifers. Movement of soil by wind or equipment would spread the inoculum. Since many conifers are susceptible to Fusarium root rot later in the season, cumulative losses could be high. Use of solar heating might have similar results, but to a lesser extent.

In this evaluation, solar-heating was the most effective treatment for weed control. The windstorm also blew many weed seeds into the study area after treatments. Even in the area treated with methyl bromide, more weeds than usual were observed under the clear polyethylene sheeting used as winter mulch over the eastern redcedar beds. Consequently, the weed control results may not adequately compare the efficacy of the treatments.

An early warming period in late winter, 1987, resulted in seedling emergence early in March. The polyethylene sheeting was removed March 12-13, 1987. Snow and cold weather followed, resulting in heavy losses to frost injury. Because of the sheltering effect of the windbreak, seedlings near the windbreak (S and C plots) were slower to emerge and were very susceptible when the frost occurred. So few seedlings survived that the treatment area was plowed under following soil sampling in July, 1987. The Nursery will try black polyethylene sheeting as mulch for subsequent eastern redcedar crops, to prevent much of the "greenhouse" warming that occurs under the clear sheeting.

Overall, fumigation with methyl bromide/chloropicrin was the most effective treatment. Based on the results of this evaluation, solar-heating and possibly polyethylene-sealed Basamid could be fairly effective substitutes for methyl bromide fumigation. Water-sealed Basamid could be used only for nematode control. Further evaluations for weed and disease control should be done with larger treatment areas and other conifer crops. The cost of treatment with polyethylene-sealed Basamid is higher than methyl bromide fumigation, but handling may be less hazardous. Solar heating is much less expensive than chemical fumigation.

Disclaimer

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145

Occurrence and Persistence of *Fusarium* within Styroblock and Ray Leach Containers[1,2]

R.L. James, R.K. Dumroese, and D.L. Wenny[3]

Abstract.--Fusarium spp. are common pathogens of containerized conifer seedlings. They often colonize inner walls of styroblock and Ray Leach® pine cell containers. Highest amounts of Fusarium were detected at the bottom of cells. As many as 95 percent of the cells at some nurseries, sampled prior to cleaning, were colonized with Fusarium. Hot water cleaning and dipping in bleach solutions reduced, but did not eliminate these fungi within containers. Fumigation with methyl bromide was no more effective than standard hot water treatments for styroblock containers; however, it was more effective in reducing levels of Fusarium within pine cells. Contaminated containers may be an important inoculum source of these pathogens for subsequent seedling crops.

INTRODUCTION

Fusarium spp. cause important diseases of containerized conifer seedlings in northern Rocky Mountain nurseries (James 1984a, 1986). Most conifer species are susceptible to these fungi, but losses are often greatest on Douglas-fir (Pseudotsuga menziesii (Beissn.) Franco), western larch (Larix occidentalis Nutt.), and Engelmann spruce (Picea engelmannii Parry)(James 1984a, 1985b; James and Gilligan 1985). Several investigations were previously conducted to help understand the disease cycle on containerized seedling stock to improve efficacy of control techniques. One important aspect of these investigations involves determining possible sources of Fusarium inoculum for seedling infection. It has been shown that seed (James 1984b, 1986, 1987), soil mixes (James 1985a), and greenhouse debris such as weeds (James and others 1987) may all act as important inoculum sources. However, experience in some nurseries has shown these potential sources do not provide enough inoculum to account for the high disease levels encountered. Therefore, investigations were conducted to ascertain the relative abundance of Fusarium inoculum on containers reused several times to grow successive crops of seedlings. Evaluations were also made on the relative efficacy of standard cleaning techniques to reduce inoculum.

MATERIALS AND METHODS

Styroblocks and Ray Leach® pine cells were analyzed from several different container nurseries in the northern Rocky Mountains (table 1). Sampling intensity varied among the nurseries, but analysis techniques were similar. Styroblock cells were selected for sampling using a random number generator. Pieces of styroblock adjacent to the inner wall were aseptically cut from selected cells and placed, inside surface down, on an agar medium selective for Fusarium (Komada 1975). Usually 2-4 pieces of styroblock were collected from each cell. Although most samples were collected from the bottom of cells, some samples were taken higher up the cell. Pine cells were sampled similarly with pieces cut from the bottom of cells. Sampling was designed to determine: 1) percentage of cells colonized with Fusarium and 2) a measure of colonization intensity which roughly indicated density of fungal propagules within cells available for infection of seedlings. Plates with container pieces were incubated at about 22-24° C under cool

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[2]Idaho Forest Wildlife and Range Experiment Station Contribution No. 404.

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fluorescent light for 5-7 days. The number of pieces from which Fusarium grew, as well as an approximation of the percentage of the piece colonized, were determined.

Table 1. Northern Rocky Mountain nurseries sampled for occurrence of Fusarium spp. on containers.

Container Type	Nursery and Location
Styroblock	Plum Creek, Pablo, MT
	Champion Timberlands, Plains, MT
	Potlatch Corporation, Lewiston, ID
	Western Forest Systems, Lewiston, ID
	University of Idaho, Moscow, ID
Ray Leach® Pine Cell	USDA Forest Service, Coeur d'Alene, ID

Cells were sampled both before and after cleaning. Cleaning techniques varied somewhat among the different nurseries. In most cases, cleaning consisted of washing containers with hot water under pressure. Some nurseries added commercial cleansers such as Saniclean® and followed the water treatment with immersions in a bleach solution. In one case, styroblocks and pine cells were fumigated with methyl bromide (under polyethylene tarps) following standard hot water cleaning. Some containers were also sampled several months after being cleaned. These containers were either stored outside or within greenhouses or warehouses.

Comparisons between "cleaned" and "uncleaned" container cells were made using standard "t" tests. Percentages underwent arc-sin transformation prior to analysis.

RESULTS AND DISCUSSION

Extent of styroblock container colonization by Fusarium spp. varied widely among the nurseries sampled (table 2). For example, levels at the Plum Creek and University of Idaho nurseries were generally lower than those at the Champion Timberlands, Potlatch, and Western Forest Systems nurseries. At Plum Creek and Potlatch nurseries there were also some differences in Fusarium colonization of containers sown with different seedlots. In most cases, standard cleaning significantly (P=0.05) reduced amount of Fusarium within containers, although high residual populations often remained. Fusarium spp. were isolated from the bottom of cells more frequently than from near the top. These fungi were also often isolated from root pieces that penetrated the side walls of cells and were not removed during cleaning.

Table 2. Occurrence of Fusarium spp. on styroblock containers from five nurseries in the northern Rocky Mountains.

			Percent of Cells Colonized with Fusarium					
		No. Cells	Prior to Cleaning			After Cleaning		
Nursery[1]	Seedlot	Sampled	Top	Bottom	Both	Top	Bottom	Both
Plum Creek	631	50	6	16	22*	0	6	6*
	632	50	12	20	28*	2	14	14*
	17045	50	6	34	36*	2	16	16*
	Totals	150	8	23	29	1	12	12
Champion	-	100	44	-	44NS	12	65	65NS
Potlatch	Spur 10	50	20	86	88*	0	18	18*
	Camp 55	50	22	92	96*	2	36	36*
	Robinson	50	18	86	86*	2	20	20*
	Blackwell	50	12	76	76*	2	18	18*
	Totals	200	18	85	86*	2	24	24*
Western Forest Systems	-	60	13	93	95*	15	65	67*
University of Idaho	FN	80	-	44	44NS	-	33	33NS

[1] See table 1 for nursery locations.

* Denotes significant differences (P=0.05) in Fusarium colonization of cells prior to and after cleaning.

NS Denotes no significant differences (P=0.05) in Fusarium colonization of cells prior to and after cleaning.

Table 3. Occurrence of Fusarium spp. on Ray Leach® pine cells from the USDA Forest Service Nursery, Coeur d'Alene, Idaho.

	Prior to Cleaning	After Cleaning	After Cleaning and Storage	All Samples
Percent Cells Infected	86*	51*	52*	65
Percent Colonization Intensity	88*	69*	72*	76

[1] Percentage of pine cell pieces colonized with Fusarium.

* Denotes significant differences (P=0.05) in Fusarium colonization of cells prior to cleaning and after cleaning or after storage.

At the USDA Forest Service Nursery, Coeur d'Alene, ID, 86 percent of pine cells sampled prior to cleaning were infected with Fusarium spp. (table 3). This was reduced to about 50 percent by standard steam cleaning. However, storage in a warehouse for several months failed to significantly reduce Fusarium populations within pine cell containers.

Treatment of styroblock containers with methyl bromide had no effect on occurrence of Fusarium (table 4). Percent of cells colonized with these fungi were similar before and after methyl bromide treatment. On the other hand, the fumigant significantly reduced percentage of pine cells which were colonized with Fusarium. Differences in effectiveness of methyl bromide between the different types of containers may be due to the ability of the fumigant to penetrate the container side walls or problems with methodology.

Table 4. Effects of methyl bromide fumigation on occurrence of Fusarium within styroblock and Ray Leach® pine cell containers.

		Percent Cells Colonized with Fusarium	
Container Type	Cells Sampled	After Cleaning	After Methyl Bromide
Styroblock	100	22.5NS	26.3NS
Pine Cells	120	55.5*	29.2*

* Denotes significant differences (P=0.05) in Fusarium colonization of cells before and after methyl bromide treatment using a standard "t" test.

NS Denotes non-significant differences (P=0.05) in Fusarium colonization of cells before and after methyl bromide treatment using a standard "t" test.

The most common species of Fusarium isolated from containers was F. oxysporum Schlect. Other major species included F. sambucinum Fuckel, F. tricinctum (Corda) Sacc. and F. acuminatum Ell. & Ev. Some of these isolates were probably pathogens whereas others were likely saprophytic. Pathogenicity tests will be required to evaluate how extensive the occurrence of pathogenic strains of Fusarium are in isolates from containers.

Our investigations indicated styroblock and pine cell containers commonly harbor Fusarium inoculum after being used to grow a crop of container seedlings. Standard techniques for cleaning containers after use are ineffective in reducing amounts of Fusarium to very low levels. Experience indicates that the more containers are used to grow several crops of seedlings, the more they become contaminated with these fungi. Several managers use older containers to grow species like ponderosa pine (Pinus ponderosa Laws.), which are not damaged by Fusarium as much as other conifer species (James and Gilligan 1988).

These investigations also showed that standard techniques of hot water, steam, and bleach treatment are relatively ineffective in reducing Fusarium to acceptable levels. Methyl bromide was also not very effective, especially in styroblocks. However, some growers in Canada have begun to use sodium metabisulfite, a chemical used in fermentation, to clean containers and report good success (Dennis and Sturrock 1988).

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Styroblock Sanitization: Results of Laboratory Assays from Trials at Several British Columbia Forest Nurseries[1]

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Abstract.—Moss and algae build-up on used styroblocks and an increase in root diseases of container-grown forest nursery seedlings in British Columbia prompted investigation of improved methods for sanitizing used styroblocks. Current block washing methods, pasteurization treatments, and several biocides were tested for their efficacy against algae and pathogenic fungi. Assays of treated styroblock pieces cultured on media in the laboratory indicate that pasteurization treatments reduced algae and virtually eliminated pathogenic fungi. Three biocides, i.e., captan, sodium metabisulfite, and methyl bromide were equally effective against pathogenic fungi. Additional testing of these and other sanitizing methods is needed to provide growers with a choice of block washing methods.

INTRODUCTION

In British Columbia forest nurseries conventional cleaning agents for used styroblocks include sodium hypochlorite (common household bleach) diluted with water and soaps specially formulated to kill moss and algae. Depending on when seedlings are lifted, styroblocks are either washed immediately after seedling removal or they are overwintered on the nursery site and washed before seed sowing. Some nurseries use sophisticated block washing machines; others use homemade dip tanks or heavy pressure hoses to wash blocks. Recent losses of seedlings to root diseases indicate that these cleaning procedures are only partially effective.

Molded from expanded polystyrene beads, styroblocks deteriorate over time, especially with heavy use. Cracks and holes which develop in the styrofoam accumulate root pieces and other organic debris which harbor fungi, algae, mosses, and insect eggs. This phenomenon cannot be overlooked in British Columbia for two important reasons: 1) enhanced production of container seedlings means prolonged use of styroblocks, e.g., blocks at some nurseries have been used for 7 to 10 seasons; and 2) an expanding 2+0 container seedling program means seedling roots are present in styroblock cavities for long periods.

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Recognizing the need for an effective cleaning procedure for used styroblocks, British Columbia Ministry of Forests and Canadian Forestry Service extension personnel, and staff at both Ministry and private nurseries undertook cooperative styroblock sanitization trials which are described here. Although the trials were originally initiated because of concerns over moss and algae build-up on used styroblocks, laboratory assay results showed that inoculum of pathogenic fungi such as Fusarium survive even rigorous styroblock washing. The first two trials tested conventional washing techniques (i.e. bleach and soap washes) against pasteurization (i.e. using heated water or other solutions or steam for a few minutes at 100°C or less to reduce microbial populations). The remaining trials tested the efficacy of several biocides as sanitizing agents.

MATERIALS AND METHODS

Trial I: Conventional Washing Versus Pasteurization

Nine block washing treatments were tested for sanitizing used styroblocks (Table 1). The styroblocks treated were of uniform age and had been used several years. The stainless steel tank used for pasteurization treatments (3 to 7) accommodated one block at a time. Tank water was heated and the temperature was maintained by using an acetylene torch to heat air being circulated by a fan through a curved steel pipe inside the tank. Treated styroblocks were randomly sampled soon after treatment by cutting ten 60 x 10 mm pieces from each block with a hand saw. The saw was sterilized with 70% ethyl alcohol after each sample. To determine post-treatment survival of fungi, 80 pieces from each treatment were transferred to petri plates containing one of four culture media (20 pieces on each medium): a Pythium-selective medium (PA) (Hendrix and Kuhlman 1965) with the antibiotic Nystatin added (Eckert and Tsao 1962); a Pythium-selective V8 juice medium (PPA) (Peninsu-Lab, Kingston, WA 1984); a Fusarium- selective medium (KM) (Komada 1975); or a general medium, Difco (Difco Laboratories, Detroit, MI) acidified potato dextrose agar (APDA). To determine survival of algae, 10 block pieces per treatment were placed in test tubes containing either Bristol's Solution (BS) (Bold 1942), a

Table 1.—Conventional washing versus pasteurization treatments of used styroblocks: Trial I.

Treatment	Description
1	Styroblocks washed[1] and dipped for 10 seconds in a tank containing a solution of Safer's DeMoss soap (1:19 v/v).
2	Styroblocks washed and dipped for 10 seconds in a tank containing a solution of sodium hypochlorite (6% household bleach) (1:11 v/v).
3	Styroblocks washed and dipped for 10 seconds in a tank containing a solution of Safer's DeMoss soap (1:19 v/v) at 30°C.
4	Styroblocks washed and dipped for 10 seconds in a tank containing a solution of Safer's DeMoss soap (1:19 v/v) at 50°C.
5	Styroblocks washed and dipped for 3 minutes in a tank containing water at 80°C.
6	Styroblocks washed and dipped for 1 minute in a tank containing water at 100°C.
7	Styroblocks washed and dipped for 3 minutes in a tank containing water at 100°C.
8	Styroblocks washed (control).
9	Styroblocks not washed (unwashed control).

[1]All styroblocks were washed with water in a block washing machine before subsequent treatment.

general medium for algae, or soil algae agar (SAA) (Poindexter 1971), a solid culture medium specific to fresh water and soil algae. Plates and tubes were incubated at room temperature under prevailing daylight for up to 8 weeks. Fungi growing from the styroblock pieces were identified as to genus and the colonies were counted. Algae colonies were not identified but were assessed as either present or absent.

Trial II: Conventional Washing Versus Pasteurization

Treatments 1, 5 and 9 from Trial I were repeated and five new pasteurization treatments were assessed (Table 2). The chamber used for treatments 5 through 7 was a standard greenhouse steam sterilizer approximately 1.07 m in diameter x 1.5 m in length. To prevent warping of the styroblocks, the steam was bled off intermittently to maintain the chamber temperature at 80 to 82°C. This meant that the styroblocks received a steam condensate treatment rather than a 100°C steam treatment. Treated styroblocks were sampled as in Trial I, but block pieces (20 per medium from each treatment) were plated on to only three culture media: KM, PA, and SAA. Numbers of fungi occurring on each styroblock piece were counted instead of counting

Table 2.—Conventional washing versus pasteurization treatments of used styroblocks: Trial II.

Treatment	Description
1	Styroblocks washed[1] and dipped for 10 seconds in a tank containing a solution of Safer's DeMoss soap (1:19 v/v).
2	Styroblocks washed and dipped for 10 seconds in a tank containing a solution of Safer's DeMoss soap (1:19 v/v) at 80°C.
3	Styroblocks washed and dipped for 1 minute in a tank containing water at 80°C.
4	Styroblocks washed and dipped for 3 minutes in a tank containing water at 80°C.
5	Styroblocks washed and placed for 3 minutes in a steam chamber (80 to 82°C @ approximately 55 kPa).
6	Styroblocks washed and placed for 5 minutes in a steam chamber (80 to 82°C @ approximately 55 kPa).
7	Styroblocks washed and placed for 3 minutes in a steam chamber (80 to 82°C; no pressure).
8	Styroblocks not washed (unwashed control).

[1]All styroblocks were washed with water in a block washing machine before subsequent treatment.

individual fungus colonies, as in Trial I. Algae colonies were assessed as in Trial I.

Biocide Trials

From fall 1987 to spring 1988 growers tested several biocides for sanitizing used styroblocks. Test conditions were not consistent due to the operational aspect of these trials. Styroblocks tested had been used for at least two growing seasons. The more promising treatments are summarized in Table 3. These included dips in captan (treatment A1) and in various concentrations of heated and non-heated solutions of sodium metabisulfite (treatments B, C1, C2, and C3, and D). Also known as anhydrous sodium metabisulfite (ABS) and sodium pyrosulfite, this free-flowing white, fine granular product is commonly used as (i) an anti-fermentative agent to kill naturally occurring yeasts in brewing and winemaking, (ii) a preservative for fruits and vegetables, and (iii) a dechlorinating agent in the production of colored paper. It is available in both technical and food grades. When mixed with water, ABS is mildly acidic and releases sulfur dioxide (SO_2) at a rate increasing with temperature. Potassium metabisulfite, which was tested in treatment A, is a product very similar to ABS. Testing continued with ABS because of its availability in commercial quantities.

Biocides tested which showed little or no effectiveness against pathogenic fungi included a detergent (G.H. Wood Detergent-

Table 3.—Summary of biocide treatments of used styroblocks.

Treatment		Description
A		Pieces of used, unwashed styroblocks dipped for 10 seconds in the following (all pieces air dried after treatment):
	1	a 0.016% solution of Captan 50WP.
	2	a 1.25% solution of potassium metabisulphite ($K_2S_2O_5$).
	3	water (control).
B		Pieces of used, unwashed styroblocks dipped for 6 seconds in the following solutions of anhydrous sodium metabisulfite (ABS) ($Na_2S_2O_5$), (a) immediately after solution was mixed or (b) 16 hours after mixing (b) (all pieces air dried after treatment):
	1a,b	ABS- 0.313% solution.
	2a,b	ABS- 0.625% solution.
	3a,b	ABS- 1.25% solution.
	4a,b	ABS- 2.5% solution.
	5a,b	ABS- 5% solution.
	6a,b	ABS- 10% solution.
	7	Pieces of used, unwashed styroblocks dipped for 6 seconds in water (control).
C		Pieces of used, unwashed styroblocks dipped for 6 seconds in the following solutions of ABS (a) immediately after solution was mixed or (b) 16 hours after mixing (all pieces air dried after treatment):
	1a,b	ABS- 2.5% solution.
	2a,b	ABS- 5% solution.
	3a,b	ABS- 10% solution.
	4	Styroblocks washed, placed under plastic tarp and fumigated with 100% methyl bromide at 0.6 kg/m^3.
	5	Pieces of used, unwashed styroblocks dipped for 6 seconds in water (control).
D		Styroblocks washed and dipped for 20 seconds in the following solutions of ABS (all blocks rinsed with water then air dried after treatment):
	1a,b,c	ABS- 1.25% solution at 4, 40 & 70°C.
	2a,b,c	ABS- 2.5% solution at 4, 40 & 70°C.
	3a,b,c	ABS- 5% solution at 4, 40 & 70°C.
	4a,b,c	ABS- 10% solution at 4, 40 & 70°C.
	5a,b,c	ABS- water at 4, 40 & 70°C (controls).

Germicide 2004), Agribrom (a bromine based, oxidizing biocide; Tayama et al. 1986), Lysofume (a disinfectant containing formaldehyde), and two metalaxyl-benomyl (Ridomil-Benlate) solutions. Treated styroblocks were sampled as in Trials I and II but block pieces (approximately 10 per medium from each treatment) were plated on to only two culture media: KM and PA. Fungi were assessed as in Trial II. Presence or absence of algae was not determined.

RESULTS AND DISCUSSION

The results of laboratory isolations for fungi and algae from used styroblocks treated in Trial I are given in Table 4. In general, pasteurization (i.e. heat) treatments were more effective for sanitizing used stryroblocks than conventional cleaning treatments (i.e. soap and bleach). Although treatment 7 (3 min at 100°C) yielded the fewest colonies of pathogenic fungi and also reduced algae, this treatment is not considered practical because 100°C distorts styroblocks. The same is true for treatment 6 (1 min at 100°C). Thus, in terms of reducing algae and pathogenic fungi, treatment 5 (3 min at 80°C) is considered the best of the nine treatments, followed by the heated soap and bleach treatments 4, 3, and 2. These results suggest that heating water and soap solutions improves their ability to kill pathogenic fungi. High temperatures (e.g. 80 and 100°C) also appear to kill algae more effectively than moderate temperatures (e.g. 50°C), soap, and bleach treatments. Given that the mechanism of sterilization by heat involves protein denaturation (Davis et al. 1973), these results are not surprising. The 0.05% sodium hypochlorite solution (treatment 2) was clearly ineffective against algae, although it reduced pathogenic fungi. Because materials containing organic matter (e.g. used styroblocks) react rapidly with the Cl_2 component of a sodium hypochlorite solution, reducing its ability to disinfect (Davis et al. 1973), bleach may not be a wise choice for sanitizing used blocks. Using more concentrated bleach solutions will get around this problem somewhat but this may not be desirable to nursery personnel. Of the four media used to isolate fungi, KM and PA were the most selective for the pathogenic fungi of interest. The soil algae agar proved better than Bristol's solution for assessing algae survival.

Isolation results from styroblocks treated in Trial II are given in Table 5. The steam chamber treatments were generally more effective at sanitizing used styroblocks than the hot water dip and conventional treatments. Treatment 7 (3 min of steam chamber, no pressure) yielded no pathogenic fungi and most block pieces were completely clean. Treatment 5 (3 min of steam chamber) was also effective against pathogenic fungi with only small amounts of Fusarium and Phoma occurring. However, these two treatments differed in their

Table 4.—Results of trial I: conventional washing versus pasteurization.

Treatment[2]	Colonies[1] of pathogenic fungi				Percentage plates (SAA) or tubes (BS) yielding algae	
	Pythium	Fusarium	Cylindro-carpon	Phoma	SAA	BS
1	21	22	10	17	100	100
2	9	6	8	16	100	100
3	7	13	3	5	100	100
4	2	11	1	7	100	100
5	0	0	0	10	50	70
6	2	4	0	7	100	70
7	0	0	0	1	100	60
8	28	35	10	15	100	100
9	13	17	16	5	100	100

[1]Total number of colonies from four media (except for treatment 9 where three media were used) and 20 plates per medium (except for treatment 5 where 10 plates per medium were used).
[2]See table 1 for descriptions of treatments.

efficacy against algae. Treament 5 was most effective against algae, followed by treatments 4 (3 min at 80°C), 3 (1 min at 80°C), and then 7. Reasons for these differences are difficult to explain. Treatments should be repeated and sample numbers increased to determine whether there was a real treatment difference. Interestingly, treatment 2 (soap at 80°C) yielded fewer pathogenic fungi than both treatments 3 (1 min at 80°C) and 1 (soap alone). These results also indicate that there is an additive cleaning effect when both soap and heat are combined. More stringent trials would determine the best combination of soap or water, exposure time, and temperature for sanitizing used styroblocks. Because laboratory assay results from treatment 6 (5 min of steam chamber) show it to be substantially less effective against fungi and algae than treatment 5 (3 min of steam chamber), it is suspected that a technical error occurred in treatment 6.

Results of laboratory assays for fungi from styroblocks treated in the Biocide Trials are given in Table 6. Pythium spp. are not included in this Table as none were isolated. Several biocide treatments were as effective as the two best pasteurization treatments in Trials I and II in that they drastically reduced or eliminated all pathogenic fungi. The captan solution (treatment A1) killed all fungi on blocks. Given that captan is a broad-spectrum protectant fungicide used on a wide range of pathogenic fungi, this result was not unexpected. While non-heated solutions of ABS ranging in concentration from 0.313 to 2.5% reduced but did not completely eliminate all fungi, concentrations of 5 and 10% generally did. Perhaps the acidity of these concentrated ABS solutions kills fungi on used blocks. Heating solutions of ABS from 4°C to 40°C and 70°C over several ranges of concentrations (i.e. 1.25 to 10%) did not appear to enhance their biocidal effect. This is in contrast to results from heated soap treatments in Trials I and II. Because the evolution of SO_2 from ABS solutions increases with temperature, it is possible that the material decomposes more rapidly at high temperatures, thus reducing its biocidal activity. Treating blocks approximately 1 day after mixing ABS solutions (treatments B and C) did not affect the material's performance. This might be important if block washing occurs over 1 or more days. Blocks treated with methyl bromide (treatment C4) also yielded no fungi in laboratory assays.

CONCLUSIONS

The results of these trials emphasize the importance of sanitizing used styroblocks and indicate that several suitable block washing techniques are available to growers. Before deciding on a particular scheme growers should consider several factors: (i) the history of disease and algae problems at the nursery; (ii) the costs of setting up a completely new or different system, or modifying their present system; and (iii) the pros and cons of the several treatments identified in these trials. For example, a pasteurization system will require some source of energy (e.g. gas, oil) for heating solutions or generating steam, plus specialized tanks and temperature gauges for maintaining and monitoring treatment conditions. While there are no hazards from toxic materials in such systems, high-temperature solutions and pressurized air must be handled carefully.

Biocide treatments are often a more practical alternative to pasteurization because they require relatively little specialized equip-

Table 5.—Results of trial II: conventional washing versus pasteurization

Treatment	Percentage[1] styroblock pieces yielding one or more pathogenic fungi				Percentage styroblock pieces yielding algae on SAA
	Pythium	Fusarium	Cylindro-carpon	Phoma	
1	7.5	82.5	27.5	47.5	100
2	0	0	7.5	0	87.5
3	0	25	5	17.5	80
4	0	2.5	0	12.5	56
5	0	2.5	0	5	55
6	5	37.5	20	40	100
7	0	0	0	0	81
8	17.5	100	62.5	50	100

[1]Percentages based on total fungi from two media and 20 plates per medium.

ment. However, these materials must be handled with extreme caution because of their potential toxic effects on nursery workers and seedlings. Product information on sodium metabisulfite warns that the material is irritating to the eyes, nose and throat and can be very irritating to the skin. Contact with skin and eyes and inhalation of dust and SO_2 should be avoided by wearing protective equipment such as rubber gloves, safety glasses or goggles and a proper respirator. Exposure to a concentration of SO_2 of 500 ppm by volume in air for a few minutes is very dangerous. A threshold limit value of 5 ppm for sulfur dioxide (concentrations in air to which nearly all workers may be repeatedly exposed during an 8-hour work day without adverse affects) was recommended by the 1968 American Conference of Governmental Industrial Hygienists (Baker and Mossman 1970). Experience with ABS in British Columbia has also shown that it can corrode block washing equipment. Materials such as methyl bromide, while a very effective biocide, are potentially very dangerous. Growers opting for this treatment must take all necessary precautions to ensure the safety of the nursery staff and, increasingly, their suburban neighbors.

To date, one small-scale trial with lettuce seeds sown into styroblocks treated with ABS concentrations of 2.5, 5, and 10% and one operational trial where several hundred blocks were washed with a 5% ABS solution, then rinsed and sown to conifers, suggest that at these concentrations, ABS is not phytotoxic.[1]

[1]Gates, W. 1988. Personal communication. British Columbia Ministry of Forests, Silviculture Branch Extension Services, Surrey Nursery, Surrey, B.C.

With nursery practices constantly changing (e.g. growing media, container types), the kinds and numbers of disease and other organisms may also change. These changes should be monitored and styroblock sanitization techniques properly tested and modified accordingly.

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Table 6.—Laboratory assay results of biocide trials.

	Percentage[1] styroblock pieces yielding pathogenic fungi		
Treatment[2]	Fusarium	Cylindrocarpon	Phoma
A1	0	0	0
A2	0	0	0
A3	40	5	0
B1a	10	20	5
B1b	25	85	30
B2a	0	50	5
B2b	0	45	5
B3a	5	45	15
B3b	0	25	30
B4a	0	20	5
B4b	0	0	0
B5a	0	0	0
B5b	0	0	0
B6a	0	0	0
B6b	0	0	0
C1a	0	0	0
C1b	0	0	0
C2a	0	0	0
C2b	0	0	0
C3a	0	0	0
C3b	0	0	0
C4	0	0	0
C5	45	20	10
D1a	0	15	25
D1b	10	20	15
D1c	10	5	0
D2a	0	5	40
D2b	0	20	35
D2c	35	25	10
D3a	0	0	0
D3b	0	5	10
D3c	0	0	0
D4a	0	0	0
D4b	0	0	15
D4c	0	0	0
D5a	25	65	25
D5b	15	90	15
D5c	5	90	0

[1]Percentages based on total fungi from two media and 10 plates per medium.
[2]See table 3 for descriptions of treatments.

Douglas-fir Seed Treatments: Effects on Seed Germination and Seedborne Organisms[1,2]

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Abstract.--Treating Douglas-fir seed prior to stratification with bleach, after stratification with hydrogen peroxide or ethanol, or soaking seed after stratification in 55.5° C water significantly reduced seedborne Fusarium levels while maintaining high cumulative germination.

INTRODUCTION

Fusarium root disease is an important problem in container nurseries of the Intermountain West. It is especially widespread and damaging to Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco). The primary source of inoculum is thought to be infested seed (James 1985a, 1986), although recent observations indicate inoculum is also carried from one year to the next in both styroblocks (James and others 1988a) and Ray Leach® pine cells (James and Gilligan 1988), even those vigorously cleaned.

Many attempts have been made to eliminate or reduce pathogenic organisms on conifer seedcoats. Many of these treatments rely on chemical sterilants, including sodium hypochlorite (Wenny and Dumroese 1987, James and Genz 1981), and hydrogen peroxide (Barnett 1976, Trappe 1961).

Recent work by Sauer and Burroughs (1986) showed corn and wheat seeds treated with 100% ethanol or sodium hypochlorite with lowered pH had decreased levels of *Fusarium*. Dodds and Roberts (1985) discuss a combination treatment for sterilizing seed for micropropagation. This treatment begins with a 1-3 minute soak in a 70% (v/v) ethanol solution followed by a soak in sodium hypochlorite.

One other approach to reducing seedborne pathogens is hot water treatments (Baker 1962). Hot water treatments have effectively been used on agricultural crops to reduce or eliminate seedborne pathogens while maintaining high germinative capacity without phytotoxic reactions (Neergaard 1977, Walker 1969). A recent innovative approach to hot water treatments is the use of microwaves to heat water to the desired temperature (Lozano and others 1986).

Because of the importance of seedborne inoculum in *Fusarium* root disease on Douglas-fir, we compared the relative efficacy of control of *Fusarium* and resultant post-treatment seed germination after use of common chemical sterilants for conifer seed and chemicals now used to sterilize seed in agricultural and micropropagation work. We also evaluated the efficacy of microwave treatments to reduce or eliminate *Fusarium* from seed coats.

MATERIALS AND METHODS

For both the chemical and microwave treatments, a northern Idaho source of Douglas-fir seed with known levels of seedborne *Fusarium* (James and others 1987) was used.

The chemical treatments consisted of six cleaning techniques (table 1), including the control (treatment 6). The control consisted of rinsing the seeds 48 hours in running tap water. Half of the seed was treated prior to cold stratification and the remainder treated after stratification. After half of the seed was treated,

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all seed was rinsed for 48 hours in a running tap water wash to ensure complete imbibition before stratification. For each treatment, seeds were placed into mesh bags to facilitate handling. These were suspended and sealed inside large plastic bags. The plastic bags were then hung inside a cooler and maintained at 2° C for 21 days. After stratification, the remaining seed was treated and all seed was rinsed 24 hours in a running tap water wash.

Table 1. Descriptions of chemical treatments used on Douglas-fir seeds.

Treatment	Description[1]
1	Soaked seeds in 95% ethanol for 10 seconds followed by a running tap water rinse.
2	Soaked seeds 10 minutes in a 2.1% sodium hypochlorite solution (2 parts commercial bleach (5.25% sodium hypochlorite) in 3 parts tap water) followed by a running tap water rinse.
3	Soaked seeds in a 3% hydrogen peroxide solution for 5 hours followed by a running tap water rinse.
4	Soaked seeds 10 minutes in a 2.1% sodium hypochlorite solution acidified with HCl to pH 6, followed by a running tap water rinse.
5	Soaked seeds in 75% (v/v) ethanol for 3 minutes, rinsed three times in tap water, and then soaked seeds in a 2.1% sodium hypochlorite solution for 10 minutes followed by a running tap water rinse.
6	Seeds rinsed for 48 hours in running tap water (control).

[1] All seed was rinsed 48 hours in running tap water prior to stratification and 24 hours after stratification.

For the microwave treatments, seeds were rinsed with running tap water for 48 hours prior to 22 days cold stratification at 3° C. Following stratification, seeds were rinsed in running tap water for 24 hours. Seeds were then placed in 300 ml distilled water within a glass beaker. The water-seed mixture was heated to varying temperatures by exposure to microwaves at the full power setting for different time periods. The microwave oven used was a Kenmore model 99701 with 1,400 watts heating power (2,450 MHz). Water temperatures were recorded before and after microwave treatments. Controls consisted of seeds placed in unheated (20° C) water. Following microwave treatments, the water was decanted and the seeds allowed to cool to room temperature before blotted dry on sterile filter paper.

Colonization of seed coats by two groups of fungi (Fusarium, and Trichoderma) was determined by aseptically placing seed on a medium selective for Fusarium (Komada 1975) following treatments. Nineteen replicates of 25 seeds (475 total) were plated on the selective medium for the chemical tests and 9 replicates of 25 seeds (225 total) for the microwave treatments. Plates were incubated at about 22° C under cool fluorescent light for 7 days after which organisms within the two groups, emerging from the seed, were tallied. Percentages of seed colonized with the two groups of organisms were calculated. Several isolates of Fusarium were grown on potato dextrose agar and carnation leaf agar for identification using the taxonomic scheme of Nelson and others (1983).

Four replicates of 100 seeds from each chemical treatment and treatment time were placed into germination trays on moistened absorbent cotton pads. Ten replicates of 15 seeds for each microwave exposure time were also placed on moistened absorbent cotton pads in petri dishes. Trays and petri dishes were incubated under 12 hours of photoperiod at 22-24° C. The containers were examined every seven days for 28 days to determine germination capacity. Seed was considered to be germinated when the radicle was as long as the seed coat.

Treatment effects on germination and the occurrence of seedcoat organisms were evaluated using a one-way analysis of variance. Significant differences among chemical treatment means were located with Duncan's new multiple range test. Tukey's multiple-range comparison test was used for analyzing the microwave treatments. All data underwent arc-sin transformation prior to analysis.

RESULTS AND DISCUSSION

The chemical treatments significantly affected the cumulative germination of the Douglas-fir seed (table 2). Germination percentages for seed treated prior to stratification (all treatments combined) were significantly lower than germination percentages for seed treated after stratification. Pre-stratification use of treatments 1 and 5 gave large fluctuations in cumulative germination percentage, often 25 to 40 percent differences between replications. Both of these treatments involved ethanol. Perhaps, for seed treated prior to stratification, and especially those treatments with ethanol, seed moisture content may have an influence. Because the seed have very low moisture contents prior to stratification, they may readily imbibe the solution carrying the chemical, resulting in tissue damage and subsequently lower germination. Conversely, the seed treated after

stratification are completely imbibed and cannot readily absorb the chemical solution. Soaking the seed prior to the pre-stratification treatment may remedy this effect.

Table 2. Chemical treatment effects on the cumulative germination of Douglas-fir seed.

Treatment[1]	Cumulative Germination at 28 Days Pre-stratification (%)	 Post-stratification (%)
1	40 d[2]	88 ab
2	88 a	87 ab
3	51 c	92 a
4	74 b	85 b
5	54 c	84 b
6	90 a	90 ab
All treatments	66 [3]	88

1 See table 1 for descriptions of treatments.

2 Within each column, means followed by the same letter are not significantly different (P = 0.05) using Duncan's new multiple range test.

3 Between pre- and post-stratification means for all treatments, the difference is significant (P = 0.01) using Duncan's new multiple range test.

In all but treatment 1, the chemical sterilants reduced seedborne Fusarium levels (table 3) when compared to the control (treatment 6). Hydrogen peroxide was the most effective chemical in reducing the levels of Fusarium on the seedcoat, supporting work by James and Genz (1981) with ponderosa pine. The combined ethanol-bleach treatment also consistently reduced Fusarium, agreeing with the work of Sauer and Burroughs (1986) on corn.

We devised a ranking procedure to determine which chemical treatment best reduced Fusarium levels, maintained high Trichoderma levels and yielded high germination percentages. In table 4, each treatment, including pre- and post-stratification applications, was given a rank according to germination percentage, Fusarium levels and Trichoderma levels. We multiplied the ranks together to obtain a score. The lowest scores received the highest ranking.

Treating the seed after stratification with hydrogen peroxide was the overall best treatment. Interestingly, our control ranked second because of its high germination capacity and the highest levels of Trichoderma. Treating seed prior to stratification with hydrogen peroxide ranked third because of its complete eradication of Fusarium, but its negative impact on germination reduces its appeal as a treatment. Treating seed prior to stratification with bleach ranked fourth, reducing Fusarium levels by 67%. Post-stratification treatment of seed with 95% ethanol for 10 seconds reduced Fusarium levels by 57% but retained nearly twice the amount of Trichoderma as the bleach treatment. In viewing the data, hydrogen peroxide, applied after stratification, bleach, applied before stratification, and the ethanol quick dip were the three treatments that significantly reduced Fusarium while maintaining the highest germination percentages.

Table 3. Chemical treatment effects on the occurrence of Fusarium and Trichoderma on seedcoats of Douglas-fir.

	Percentage Seedcoat Colonization			
	Fusarium		Trichoderma	
Treatment[1]	Pre[2]	Post[3]	Pre	Post
1	6.6 f[4]	2.1 d	82 b	30 c
2	1.6 c	4.2 e	14 d	21 d
3	0.0 a	0.2 a	28 c	52 b
4	2.8 d	0.9 c	3 f	5 f
5	0.5 b	0.9 b	5 e	10 e
6	4.5 e	5.2 f	90 a	80 a

1 See table 1 for descriptions of treatments.

2 Pre = treatments performed prior to seed stratification.

3 Post = treatments performed after seed stratification.

4 Within each column, means followed by the same letter are not significantly different (P = 0.05) using Duncan's new multiple range test.

All chemical treatments, and the microwave treatment, were also effective in significantly reducing the levels of Trichoderma on seedcoats (tables 3 and 5). Since Trichoderma are common antagonists against Fusarium spp. (Papavizas 1985), reducing their occurrence on seed may not be desirable. This is especially true if Fusarium inoculum is introduced into containerized seedlings from sources other than seed, such as containers (James 1987, James and others 1988a) or soil mixes (James 1985b).

Effects of microwave hot water treatments on seed germination and Fusarium and Trichoderma levels on Douglas-fir seedcoats are summarized in table 5. No seed germinated after 120 seconds of exposure (66.5°+ C), although germination was not significantly reduced by exposures of 90 seconds

Table 4. Rank of treatment efficacy based on cumulative germination and *Fusarium* and *Trichoderma* levels.

Treatment[1]	Cumulative germination		*Fusarium* levels		*Trichoderma* levels		Overall ranking computation	
	percent[2]	rank	percent	rank	percent	rank	formula	rank
1 pre	40 f	11	6.6 i	11	82 b	2	(11*11*2) = 242	8
1 post	88 abc	4	2.1 e	7	30 d	5	(4*7*5) = 140	5
2 pre	88 abc	3	1.6 e	6	14 g	7	(3*6*7) = 126	4
2 post	87 bc	5	4.2 g	9	21 f	6	(5*9*6) = 270	9
3 pre	51 e	10	0.0 a	1	28 e	4	(10*1*4) = 40	3
3 post	92 a	1	0.2 b	2	52 c	3	(1*2*3) = 6	1
4 pre	74 d	8	2.8 f	8	3 j	11	(8*8*11) = 704	11
4 post	85 bc	6	0.9 d	4	5 i	9	(6*4*9) = 216	6
5 pre	54 e	9	0.5 c	3	5 i	10	(9*3*10) = 270	9
5 post	84 c	7	0.9 d	4	10 h	8	(7*4*8) = 224	7
6	90 ab	2	4.8 h	10	85 a	1	(2*10*1) = 20	2

1 See table 1 for descriptions of treatments. Pre = treatments performed prior to seed stratification. Post = treatments performed after seed stratification.

2 Within the percent columns, means followed by the same letter are not significantly different (P = 0.05) using Duncan's Multiple Range Comparison Test.

Table 5. Effects of microwave hot water treatments on occurrence of *Fusarium* and *Trichoderma* on Douglas-fir seed, and cumulative germination percentage of Douglas-fir seed[1].

Exposure time (sec.)	Max. water temperature (degrees C)	Seeds with *Fusarium* (%)	Seeds with *Trichoderma* (%)	28-day cumulative germination (%)
0	20.0	3.1 a[2]	98.2 a	90 a
60	43.0	1.8 ab	96.9 a	87 a
90	55.5	0.4 b	46.7 b	86 a
120	66.5	0.0 b	0.4 c	0 b
150	77.0	0.0 b	0.4 c	0 b
180	88.5	0.0 b	0.0 c	0 b

1 See James and others (1988b).

2 Within each column, means followed by the same letter are not significantly different (P = 0.05) using Tukey's multiple-range comparison test.

(55.5° C) or less. Unfortunately, the exposure time needed to eliminate all Fusarium from seed also eliminated seed viability. However, the 90 second treatment reduced Fusarium levels to almost negligible amounts (0.4 percent) and did not significantly reduce seed germination. Treatments somewhere between 60 and 90 seconds (43° and 55.5° C) may be best for practical applications. Additional tests are necessary to locate this thermal "window" more precisely.

Treatments of agricultural seeds using vegetable oils, such as sunflower, soybean and maize oils as the medium for heat treatment instead of water, have been effective (Ryndji and others 1987, Zinnen and Sinclair 1982). The major advantage of vegetable oils over water is reduced seed imbibition of the heated medium and resulting toxicity to the embryo. There is currently no information available as to the responses of conifer seeds to such treatments, but evaluations may be beneficial because of the toxicity of hot water to Douglas-fir seed.

It is probable that other conifer species, and also other Douglas-fir seedlots, will respond differently to the chemical and hot water treatments. Larger quantities of seed treated at one time may also react differently. Additional tests are required to establish safe guidelines.

CONCLUSIONS

Sterilizing Douglas-fir seed before stratification, except with bleach, had a negative impact on germination. Conversely, seed sterilized after stratification maintained high germination percentages. Treating seed prior to stratification with bleach, after stratification with hydrogen peroxide or ethanol, or after stratification in hot water (55.5° C) significantly reduced seedborne Fusarium and Trichoderma levels while maintaining high cumulative germination.

MANAGEMENT IMPLICATIONS

We need to develop a method for rapid identification of pathogenic Fusarium. Knowing whether the seedborne inoculum is pathogenic or not would help the nursery manager decide if a seed coat sterilization treatment is necessary.

Because of this uncertainty, problems with seed from unknown collection sources, and favorable operational results, the University of Idaho Forest Research Nursery uses the bleach treatment before stratification to reduce seedborne Fusarium levels on pine and Douglas-fir seeds (Wenny and Dumroese 1987). However, for research where nearly complete eradication of Fusarium is essential (i.e. pathogenicity tests), the after stratification hydrogen peroxide treatment appears best. Growers with the benefit of sowing vigorously germinating seedlots with very low levels of seedborne inoculum are probably better off not reducing their seedborne levels of antaganistic Trichoderma with a seed sterilization treatment.

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Douglas-fir Dieback[1]

Lynn D. Husted[2]

Abstract.--Dieback of container Douglas-fir germinants is caused by a minor root pathogen. The incidence and severity of dieback are strongly influenced by (1) germinant susceptibility to the pathogen, highest the first few weeks after germination, and by (2) the growing environment, particularly moisture content, temperature and pH of the growing mix.

INTRODUCTION

For the past five years, nursery growers have observed a growth problem, termed needle dieback, in container-grown Douglas-fir seedlings. Dieback occurs in patches throughout Douglas-fir seedlots and may result in cull losses of 0-25% depending upon the nursery, sowing date and year. Dieback symptoms including stunted shoot growth, needle chlorosis, and dieback of needles from the tips to the bases. These symptoms are first noticed when the seedlings are a few centimetres tall. The root systems of dieback seedlings appear normal, exhibiting none of the external symptoms associated with root diseases.

This poster summarizes the results of Douglas-fir dieback research funded by the Canada-British Columbia Forest Resource Development Agreement. For more information, a file report is available from Dr. J. Sutherland, Pacific Forestry Centre, Canadian Forestry Service, Victoria, B.C., Canada.

RESULTS

Douglas-fir dieback is caused by a minor root pathogen. However, the incidence and severity of dieback damage depends on the growing environment and the susceptibility of Douglas-fir germinants to the pathogen (fig. 1).

Minor Root Pathogen

A minor root pathogen, probably *Pythium ultimum*[3], causes dieback in Douglas-fir germinants. This conclusion is based on the following observations.

(1) Autoclaving growing medium or drenching it with a systemic fungicide, fosetyl aluminum, eliminates or significantly reduces the incidence of dieback.

(2) *Pythium* has been isolated consistently from surface-sterilized roots of dieback seedlings.

(3) *Pythium* oospores isolated from dieback seedling roots were cultured and used to inoculate sterile Douglas-fir seeds sown into autoclaved peat:vermiculite (PV) growing mix. *Pythium*-inoculated seedlings developed dieback symptoms. No dieback symptoms developed on control seedlings which were inoculated with heat-killed Pythium cultures. Microscopic examination of *Pythium* oospores isolated from inoculated dieback seedlings showed that they were similar to those of the original inoculum cultures.

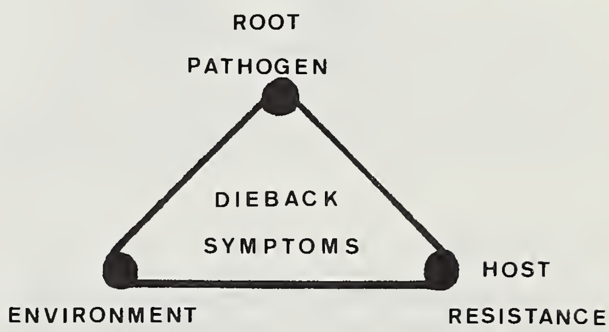

Figure 1.--Douglas-fir dieback as a minor root pathogen x host x environment interaction.

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[1]Poster presented at the Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia and Intermountain Forest Nursery Association Meeting (Vernon, B.C., Canada, August 8-11, 1988).

[2]Lynn D. Husted is a contract research scientist for Canadian Pacific Forest Products Limited, Victoria, B.C., Canada.

[3]Identified by Dr. H. Hartmann, M.B. Research and Development, Sidney, B.C., Canada.

(4) There are numerous reports of subclinical damage caused by a variety of *Pythium* species (Hodges 1985, Horshman 1986, Kobriger and Hagedorn 1984). Subclinical damage is characterized by stunting and growth losses in plants which have normal-appearing roots with no external symptoms of root rot.

Minor root pathogens, such as *Pythium*, are generally restricted to juvenile root tissues such as root hairs, root tips or cortical cells (Salt 1979). In Douglas-fir germinants, *Pythium* seriously reduces root hair development (figs. 2 and 3). Damage to root hairs is easily overlooked and may be of a temporary nature because root hairs may live only a few hours, days or weeks (Kramer and Kozlowski 1979). However, root hairs can comprise 50% of the total root surface area of a seedling (Kozlowski and Scholtes 1948) and therefore, contribute significantly to water and nutrient absorption.

Environment and Host Susceptibility

The degree of damage caused by minor root pathogens typically depends on the growing environment and host plant vigor (Salt 1979). Seedling age, growing mix temperature, moisture content and acidity (pH) are important factors influencing the incidence of Douglas-fir dieback in container nurseries.

Seedling Age

Percent germination is not affected by the presence of the dieback pathogen. Dieback symptoms appear two to three weeks after germination. Susceptibility to dieback decreases as seedlings age. One-week-old germinants transplanted into growing medium containing the dieback pathogen are very susceptible to the disease; 80-90% will exhibit dieback symptoms. In contrast, eight-week-old seedlings transplanted into growing mix containing the dieback pathogen do not develop dieback symptoms.

Figure 2.--Micrographs of root hair development in a healthy Douglas-fir germinant.

Figure 3.--Micrographs of root hair development in a dieback Douglas-fir germinant.

Growing Mix Temperature and Moisture

Moisture stress and high root-zone temperatures appeared to influence the incidence and severity of dieback in container nurseries. In order to determine the effects of growing mix temperature and moisture on dieback incidence, Douglas-fir germinants were transplanted into sterilized PV or sterilized PV inoculated with the dieback pathogen. The germinants were grown at two root-zone temperatures (20 and 30°C) and at three levels of moisture stress: (1) none [moisture content (MC) of medium 575%], (2) light (MC of medium 375%), and (3) moderate (MC of medium 140%).

Three weeks after germination, all seedlings grown in the sterilized PV with no inoculum appeared healthy. In the sterilized PV containing the dieback pathogen, the incidence of dieback increased with growing mix temperature and moisture stress (figs. 4 and 5). Root-zone temperature also affected the severity of dieback symptoms. At 20°C, dieback seedlings were stunted and had needle dieback; at 30°C, most dieback seedlings died.

Growing Mix pH

Douglas-fir seed was sown into 3:1 mixtures of peat:vermiculite adjusted with dolomite lime to initial pH values of 4.0, 5.0, or 6.0. During the six week experiment, pH rose 0.8 to 1.0 units in each mix. All mixes contained micronutrients. The development of dieback symptoms was strongly influenced by the initial pH of the growing mix. Mean dieback incidences (three replicates) for pH 4.0, 5.0 and 6.0 were 94%, 10% and 4%, respectively.

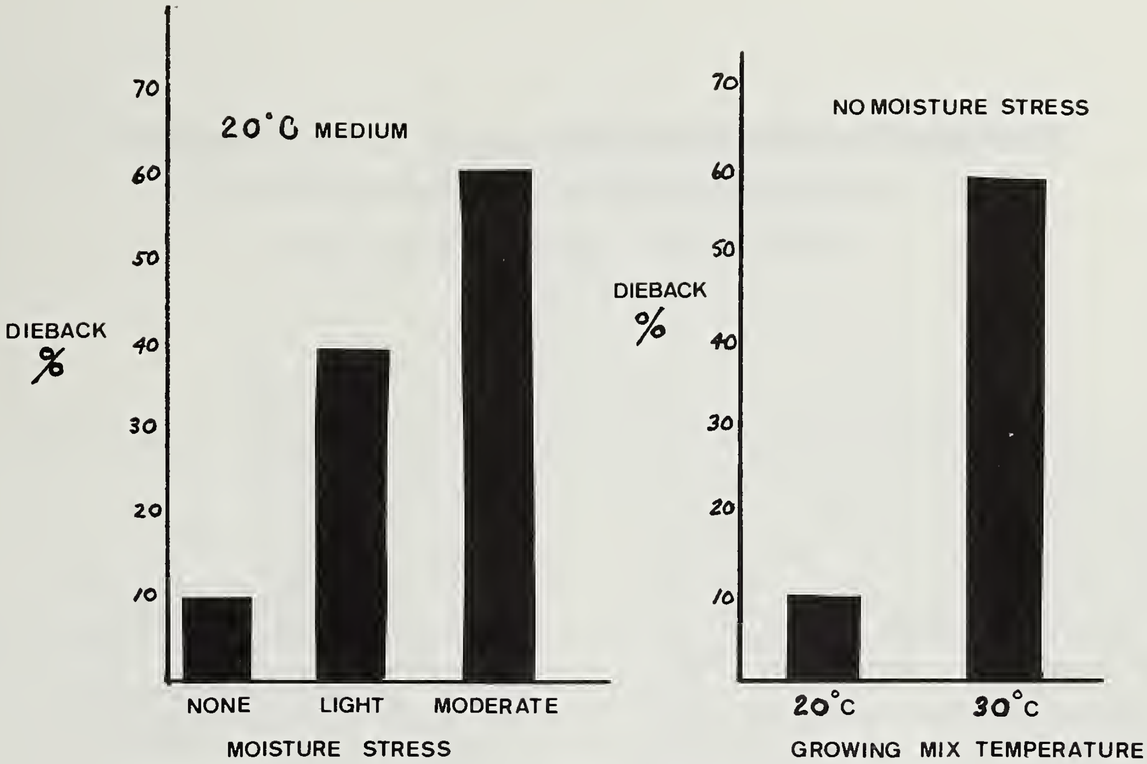

Figure 4.--Effects of growing mix temperature and moisture content on the incidence of Douglas-fir dieback.

In B.C. nurseries, a growing mix pH of 4.0 is not unusual during the first few weeks after sowing[4]. Low pH is associated with low calcium availability. Either of these factors may increase dieback incidence by (1) decreasing host vigor, or (2) decreasing bacterial competition for nutrients. Elad and Chet (1987) reported that the presence of bacteria along the roots of susceptible host plants reduced the establishment of *Pythium* along the roots; the bacteria appear to compete successfully with *Pythium* for nutrients. Low availability of calcium may also favor the germination of *Pythium* spores (Kao and Ko 1986, Qian and Johnson 1987).

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Update on the Environmental Impact Statement for Pest Management at the Federal Nurseries in the Pacific Northwest Region[1]

Sally J. Campbell[2]

The Nursery Environmental Impact Statement (EIS) is a document which will present an analysis of the environmental impacts of managing weeds, diseases, insects, and animal damage at the Wind River Nursery, Bend Nursery, Dorena Tree Improvement Center, and the J. Herbert Stone Nursery in the Pacific Northwest Region. The issues which will drive the analysis are human health, environmental quality, and economics. Several alternatives for nursery pest management will be compared and a preferred alternative will be selected upon completion of the document. The alternatives are:

1. Current pest management with the use of herbicides (situation as it existed before the 1984 herbicide ban).
2. Current pest management without the use of herbicides (situation as it existed after the 1984 herbicide ban).
3. Pest management with no chemical pesticides. Biological and cultural control methods used within the framework of a formal decision-making process.
4. Pest management using chemical pesticides as a last option after other methods have failed, within the framework of a formal decision-making process.
5. Integrated pest management using all methods, within the framework of a formal decision-making process.

The document will be completed by March 1989, and implementation of the preferred alternative will begin in 1989 at all of the Pacific Northwest Federal nurseries.

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[1]Poster presented at Combined Western Forest Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association meeting; Vernon, British Columbia, August 8-11, 1988.

[2]Sally J. Campbell, Plant Pathologist, USDA Forest Service, Portland, Oregon.

245 Greenhouse Transplants for Bareroot Stock Production[1]

Robert A. Klapprat[2]

Abstract.--The propagation of tree seedlings at very dense spacing in greenhouses, then transplanted with an automatic transplanter into nursery beds, has become an operational method of producing forest regeneration stock at the Thunder Bay Forest Nursery. This system optimizes; reliability, production capacity, seed utilization, stock quality and operating efficiency

The stock requested by clients of the Thunder Bay Forest Nursery is mainly the black spruce species and the transplant stock type. Its production is a two phase process; the seedling phase and the transplant phase. It has been the seedling stage that has presented extraordinary production challenges at this Nursery.

When black spruce seed is sown directly into the soils of the Nursery many elements and conditions over which we have little or no control immediately begin to work against the successful production of that crop. Even some of the precautions taken to alleviate a particular threat can have detrimental effects as well. Some of these concerns include;
seed placement which can be: too shallow, too deep, too close together or delayed,
soil erosion which can result from: wind (saltation, rain (wash-out and compaction), run-off (wash-out), irrigation (wash-out and compaction),
hydro mulch which can be restrictive to emergence
shading which can impede surveillance restrict or limit applications, destroy seedlings from frame legs, create drip-lines from wires, restrict machine manoeverability,
hand weeding which can cause trampling uprooting seedlings with the weeds, and compaction,
pre-emergent and post-emergent herbicides can be somewhat toxic to tree seedlings,
insects can cause deformity and mortality from feeding,
diseases such as damping-off and snow mould can cause deformity and mortality,
birds can cause deformity and mortality from their feeding,
traffic from people and machines can cause compaction, trampling, deformity and mortality,
weather conditions may retard germination and growth, can cause frost killing and frost heaving and flooding can cause destruction and mortality.

All of these elements are not constant. They do not have the same impact each year. During some years the combined impact may be significantly greater than in other years. Though our long term records indicate the necessity to place up to 12 seeds in the ground for each tree shipped, the fluctuations in any one year can cause drastic detractions from our reliability in achieving targets. It is this concern which prompted us to move toward a more controlled method of producing transplants; hence greenhouse transplants.

Reliability in meeting targets is achieved by more successfully nurturing germinating seeds to become surviving trees. The use of seed is optimized since each seed is placed in a micro-environment that is conducive to growth hence a greater survival percentage can be expected. Production costs are reduced as the very slow and costly processes of harvesting, grading, sorting and packaging seedlings for transplanting, and transplanting with semi-mechanical equipment are eliminated. Stock quality is improved as the stresses induced from root pruning, exposure time and nutrient depletion during transplanting as well as deformities resulting from the planting processes and frost heaving are eliminated. The production capacity of the Nursery is increased as the rotation period is reduced to two years and as compartments formerly used as seed beds can now be transplants. Harvesting costs are expected to be reduced from resulting uniformity as bed-run harvests become a reality and bulk

[1]Paper presented at the 1988 Conference, Western Forest Nursery Council Forest Nursery Association of British Columbia (Vernon Recreation Complex Auditorium, August 8-11, 1988).

[2]Robert A. Klapprat is Superintendent of The Thunder Bay Forest Nursery, Ontario Ministry of Natural Resources, Thunder Bay, Ontario, P7C 4T9 Canada.

shipments are accepted.

The decision to proceed with the Techniculture system is the culmination of many tests, trials and investigations on container types and handling systems over several years. Different products had different advantages to offer for the various stages in the production process. But the one that pulled it all together from our point of view was the Techniculture system as developed by Castle & Cooke of California. Some of the considerations which made the system particularly attractive to us include:

The medium is ready to use:
There is no necessity to purchase several components such as peat, vermiculite, perlite, wetting agents, etc., which must be accurately blended and mixed in special mixing vats. Also avoided are the filling lines and warehousing requirements of alternate soil medium and tray choices.

Greenhouse space optimized;
Each tray has 400 cavities. A typical 9.2 x 42.7 meter greenhouse will hold approximately 1.2 MM trees in a single crop. With three crops per year, one house will produce 3.6 MM trees.

The design and configuration are culturally correct;
The plug shape can accommodate the tap root of coniferous seedlings. The indentation/cavity within the plug permits ideal seed placement for even germination and growth.

The system lends itself to mechanization;
Since plugs retain their conformity they can be handled mechanically. The square dimensions of the trays permit easier alignment at all stages of production and handling.

The concept is a "system;
All components are readily available to assemble a system: trays, seeder, benching, handling, transplanting.

USING THE TECHNICULTURE SYSTEM

Central to the Techniculture system is the stabilized growing medium. It is a dimensionally stable mix of peat moss and a non-toxic binder. This medium is formed in tapered cavities which are 1.27 cm x 4.45 cm. Each resultant plug has a formed indentation which is 3.2 cm in diameter and 8 mm in depth. There are 400 plugs in each tray which has dimensions of 32.1 x 32.1 x 3.8 cm.

When trays are received from the plant in California they are already filled with the rooting medium. They usually arrive via tractor trailer and are packed on plastic wrapped pallets. The medium is moist from the manufacturing process and it is best kept that way since the plugs contract as they dry. Though trays are usually used within a short time of their arrival, we have on occasion stored them for several months without any fungal growth on their surface or any other deterioration in quality. Until recently we have discarded empty trays after use as it was not economical to return them to California. With the large quantities we are using now it is possible to make up a full load of reusable trays thus creating a back-haul for the carrier and making their return economically worthwhile.

Upon receipt at the Nursery, the trays are covered with a thin layer of the medium. This is a result of the filling process. It is actually beneficial in holding plugs from falling out prior to seeding. At seeding time this layer of material is removed with a wide putty knife. For the seeding process, a template with funnel shaped holes is placed over the tray and seeds are dropped into the cavities by the Vancouver Bio-Machine seeder. After seeding, the trays are moved by conveyor to the greenhouses where they are placed on a benching system made of Y-bar. This support system allows trays to be slid along the sides of the greenhouse. This also eases the handling during the thinning and removal processes. It takes about 14 hours to seed and fill one greenhouse.

Immediately after filling the greenhouse, irrigation begins. Frequent misting promotes rapid and even germination which, for black spruce takes 7-10 days. Because each seed is placed in an identical micro-environment, that is, a cavity which is 8 mm in depth and 3.2 mm in diameter with no mulch covering, germination and growth is usually very uniform. This is particularly beneficial in a crop like spruce which has tremendous genetic variability.

As soon as germination is complete and the seed caps are dropped and before lateral roots begin to develop, the crop is thinned. It is important that the stocking is reduced to one seedling per cavity since multiple seedlings per plug would result in multiples after transplanting and would not be acceptable for shipment after harvesting. This is a laborious time consuming operation which we hope to eliminate through more accurate seed placement and improved seed quality.

By the time thinning is completed lateral roots begin to develop and fertilizer is applied in solution with irrigation water. We begin with a "starter" fertilizer (11-41-8) at 50 ppm for 2 weeks, then switch to "grower" fertilizer (20-8-20) at 100 ppm N for the active growing period and finally a "finisher" fertilizer (8-20-30) at 40 ppm N during the conditioning period.

Three crops are grown in the greenhouses each year. The spring crop is grown from mid-March until late May/early June after which it is taken directly to the Nursery for transplanting. As the greenhouse is vacated of this crop the second crop is seeded and placed in the greenhouse. Dormancy is induced in that crop by July 31 and it is moved to outdoor holding areas by mid-August when the third crop is seeded and placed in the greenhouse. Dormancy is induced by mid-October and temperatures

are reduced in the greenhouse in order to promote hardiness in the crop.

Frost hardiness is monitored after November 1, so that the crop can be transferred to cold storage after there have been two successive weeks of freezing tests with index of injury of 5% or less at -10°C.

For overwinter storage, the trays are placed vertically in boxes which are poly sealed and placed on pallets. The storage temperature is held at -2°C until removal for transplanting the following May.

Stock is removed from the frozen storage a day or two before transplanting to permit the plugs to thaw. They are then given a good watering prior to transferring to the field for transplanting.

For subsequent transport and handling trays are placed in large cartridges. This permits easy transport to the field by truck and handling with a fork lift. The cartridges are placed on carrying platforms on the transplanter and the transplanting operation can commence.

The transplanter is a diesel powered, self propelled four wheel hydrostatically driven short turning carrier unit which supports eight high speed planting heads that can extract and transplant trees from trays that are inserted into the mechanism from the two large cartridges by two operators.

The field speed of the machine can be up to 2.0 kilometers per hour and it has a capacity of planting from 160-180 thousand trees per hour. As comparison the Holland transplanter moves at about 3-3.5 meters per minute and can plant about 15 thousand trees per hour. As already indicated, the overwintered crops are planted in a dormant condition in May and the current crop is planted in an active condition in June when the danger of frost is passed.

The transplanted stock is grown in the fields of the bare root nursery for two years prior to harvesting for shipment for plantation establishment.

Production Aspects of Mini-Plug Transplants[1]

Stephen M. Hee, Thomas S. Stevens, and Douglas C. Walch[2]

Abstract.--The MINI-PLUG™ transplant system allows the production of high quality Douglas fir transplants within a period of one or one and a half years. This patented system which was originally developed for the vegetable industry has been adapted for forestry by Weyerhaeuser Company under an exclusive use agreement from Grower's Transplanting, Inc. Along with reduced production time, this system offers substantial labor savings through the use of a highly automated transplanting machine. The paper describes the production aspects of this system.

INTRODUCTION

In 1983 Weyerhaeuser Company of Tacoma, Washington teamed up with Grower's Transplanting, Inc. (GTI) of Salinas, California to adapt GTI's automatic vegetable transplanting system to the production of forest seedlings. Our vision at that time was to be able to produce a Douglas fir seedling capable of high survival rates within one growing season and do this at a cost which would be competitive with other classes of seedlings. This paper describes our progress to date relative to the production aspects of this new type of seedling. Field performance results which have been highly satisfactory are reported by Tanaka elsewhere in these proceedings (Tanaka, 1988). Weyerhaeuser Company currently holds exclusive rights to use this patented system in all forestry applications.

GREENHOUSE PHASE

The MINI-PLUG™ production cycle utilizes both the controlled greenhouse environment and the natural climate of the bareroot nursery to produce a vigorous, hardy transplant in one year. Figure 1 outlines several growth cycles for MINI-PLUG™ transplants. Seedlings for the standard cycle are sown into the greenhouse in January and transplanted into the nursery in May of the same year. These seedlings will be ready for lifting the following winter. A second cycle which produces a MINI-PLUG™ transplant in 1.5 years can be initiated by sowing during early summer and transplanting in the fall. Combining the winter sow and summer sow cycles gives the greenhouse the opportunity for double cropping.

Producing a high percentage of fully rooted seedlings is a primary focus during the greenhouse phase of MINI-PLUG™ production. It is important that the root matrix of the seedlings hold their integrity during the transplant process because the plugs are punched out the bottom of the growing tray by a spear shaped probe. To allow the plants to be set directly into the ground, the tray is specially designed with an open bottom. The tray is also designed to serve as a magazine for the plugs so that a whole tray of plants is loaded at a time (Branch 1986).

The 26.5 inch by 6.75 inch tray has 256 cells which are approximately 1 cubic inch per cell. Because of this relatively small volume, it is important to fully fill each cell with growing medium so that no air pockets exist. To accomplish this goal, we designed and modified a tray filler which fills the cells in a stepwise fashion. Empty trays are placed on a conveyor holding a series of three bins containing peat. As the trays pass underneath each bin a layer of peat drops into the trays. Immediately following each bin, a specially designed packing wheel with cogs rotate into the cells compressing the peat as the tray passes underneath. One wheel is necessary for each row of cells. The progressive sequence of filling and compressing results in a uniformly filled tray which will enable the development of a fully extractable root system.

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[1]Paper presented at the joint symposium of Western Nursery Council and Forest Nursery Association of British Columbia held at Vernon, B.C., Canada, August 9-11, 1988.
[2]Authors are respectively, Manager - Western Nurseries, Nursery Technologist and Greenhouse Technologist for Weyerhaeuser Company, Rochester, Washington.

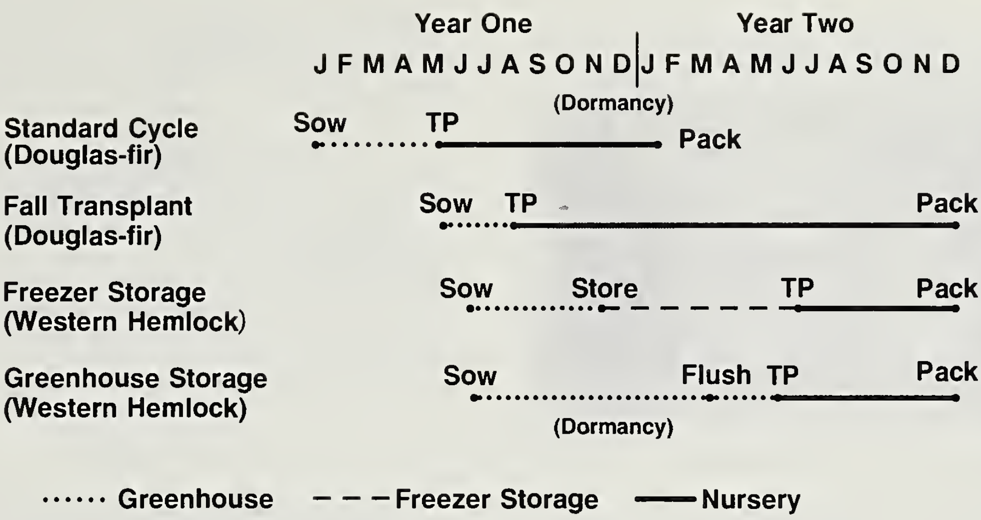

Figure 1.--MINI-PLUG™ transplant production cycles.

To facilitate air pruning of the roots, the trays are supported by extruded aluminum supports which are mounted on top of the growing beds. The beds are enclosed on all sides and warm air is pumped in below to provide heat. The trays are thus warmed by the rising heat.

Once the seedlings have completed their development in the greenhouse they are ready to be transported to the nursery. Full trays of plants are loaded into plywood bins. Each bin holds six trays and the bins are stacked onto pallets which hold nine bins per pallet. The palletized bin system will hold 54 trays or 13,824 seedlings. The pallets may be moved with a pallet jack or a forklift. The palletized system provides a transport unit which can be placed directly on the transplanter.

BAREROOT PHASE

Palletized bins of MINI-PLUG™ starters arriving from the greenhouse operation are directly loaded onto the transplanter using a forklift. The pallets are placed on an aluminum roller conveyor, which allows them to be easily moved into place. The transplanter is currently designed to hold three banded pallets or approximately 42,000 MINI-PLUG™ starters.

The basic transplanter crew consists of a tractor driver, tray handler, and transplanter operator. One or two additional people follow the machine and replant poorly placed seedlings. These crew members can also assist in the loading of the transplanter at the ends of beds.

The transplanter is 3-point mounted on an 80-horsepower tractor (fig. 2). The MINI-PLUG™ starters are pneumatically planted; consequently, two 10-horsepower air compressors are required. These compressors are mounted on the front of the tractor and they are driven by the tractor engine (Branch 1987).

Each patented seedling starter tray acts as a magazine; therefore, 256 seedling cells are loaded into the machine at one time. One side of the starter tray is notched between each starter cell. These notches are used by an indexing cylinder to feed the tray through the transplanter. The indexing cylinder cycles 80-90 times per minute and with each cycle eight air driven plant setters spear a MINI-PLUG™ starter cell. While holding the seedlings vertical, the setter spears push the starter cells through the bottomless trays into the furrows created by the shoes. Water is injected into the furrow just ahead of the actual planting of the MINI-PLUG™ starters. The MINI-PLUG™ starters are held vertically by the setter spears, while the furrow shoes continue to move forward and soil is packed around the cells. The setter spears then retract and both the trays and setters return to position over the shoes, ready to plant another complement of eight seedlings (figs. 3-6). A unique feature of this machine is that during the planting process the carriage holding the trays and setters moves backwards at the same speed the tractor is moving forward. Thus, the MINI-PLUG™ starters are planted at zero relative ground speed, resulting in high quality planting. The empty trays are indexed out of the machine, flipped 90 degrees on side and conveyed back to the tray loader for placement into an empty bin (Branch 1987).

Figure 2.--MINI-PLUG™ tranplanter and tractor.

Precise adjustment of the planter mechanism to the surface of the transplant beds is required as the MINI-PLUG™ starters are only about 1 inch in length. To accomplish this, hydraulic cylinders were installed in the link arms of the three point hitch to provide side to side adjustment and a hydraulic cylinder was mounted on the ski frame at the rear to give fore and aft trim. The controls for this bed trim system are mounted at the rear of the transplanter to allow quick and precise adjustment by the machine operator. In contrast, most transplanters are manually adjusted or hydraulically adjusted by the tractor operator, who is in a poor position to judge bed conditions and planting quality.

During transplanting, water can be injected into each furrow just prior to the planting of the MINI-PLUG™ starter cells. The water system consists of twin two hundred gallon water tanks mounted on the tractor and a hydraulically driven tube pump located on the transplanter. The quantity of water flowing into the furrows is adjusted depending on soil moisture and weather conditions. This water system eliminates the need for immediate irrigation to reduce transplanting shock. Thus, soil preparation and transplanting activities are not interrupted by irrigation.

Once transplanted in the bareroot nursery, the MINI-PLUG™ transplants are culturally treated similar to other transplant crops. These seedlings are lifted and shipped to the field after one growing season in the bareroot nursery. Upon lifting, these seedlings exhibit a dense mop-like root system having a profusion of lateral roots. Though somewhat more compact than other seedlings, MINI-PLUG™ transplants have an excellent shoot to root-ratio (table 1).

SUMMARY

MINI-PLUG™ transplants have excellent shoot to root ratios, which result in high survival and growth rates. In the field high outplanting production rates are possible because of their compact size and mop-like root system. The MINI-PLUG™ transplant system requires a shorter production cycle (1-1.5 years) than other transplant stock types (2-3 years). A higher level of growing space utilization can be achieved as less space is required in both the greenhouse (2218 starters/sq meter) and the nursery (113 transplants/sq meter) than other transplant stock types. Because of the short greenhouse growth cycle more than one crop per year may be grown in the greenhouse. The MINI-PLUG™ transplanting system is highly automated with the capability of transplanting 40,000 MINI-PLUG™ starters per hour. Transplant shock is reduced because the MINI-PLUG™ starters are provided with in-furrow watering as part of the transplanting process. Transplanting costs are less as a result of a lower labor requirement; and total seedling costs per thousand can be further reduced by the increased stocking level in the nursery beds.

Table 1.--Morphological comparison of different stock types from 1988 tests.

Stock Type	Height (cm)	Caliper (mm)	Shoot/Root Ratio (Dry Weight)
[1]MPT-S	20.6	4.3	1.67
[2]MPT-F	47.0	7.6	
2+0	37.0	5.4	2.94
1+1	52.2	6.9	2.86
2+1	51.9	7.4	2.33

[1]MPT-S Spring Transplanted Mini-Plug™ Transplant

[2]MPT-F Fall Transplanted Mini-Plug™ Transplant

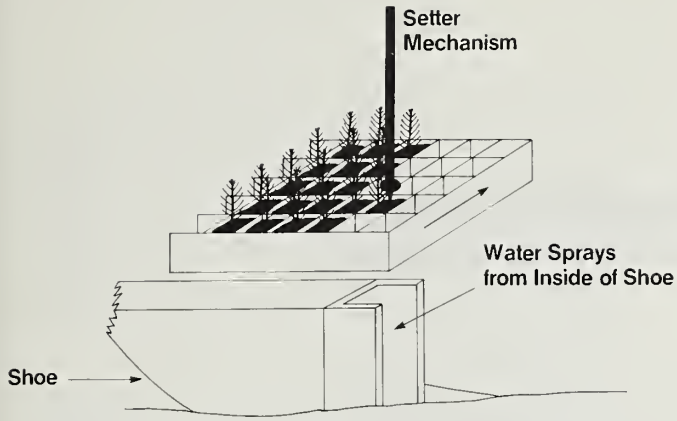

Figure 3.--Tray has just indexed to position new starter cell under setter mechanism.

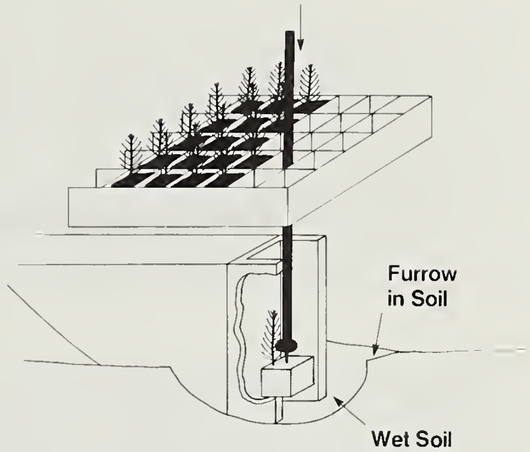

Figure 4.--Spear extends into starter cell to hold it vertical while cell is pushed through tray into furrow behind shoe.

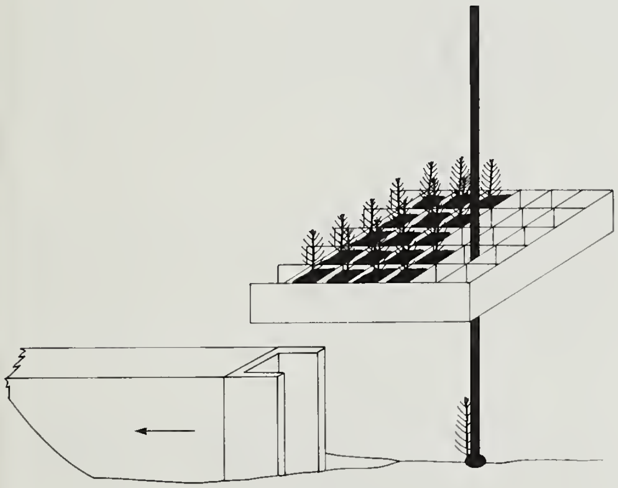

Figure 5.--Spear holds starter cell upright as shoe moves forward and soil closes around cell.

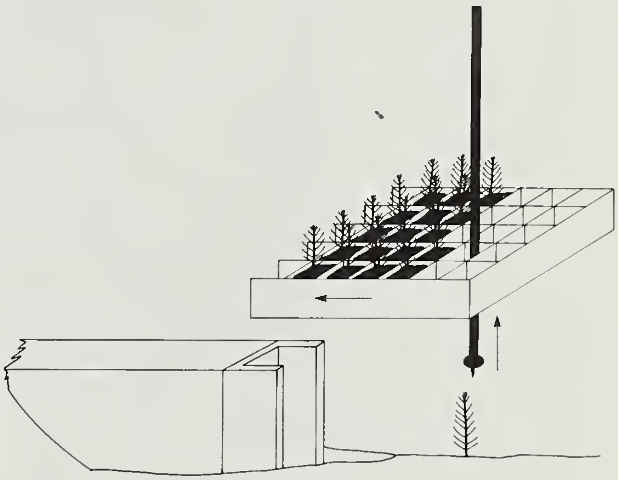

Figure 6.--Mini-Plug™ starter has been planted, spear retracts and setter mechanism returns to position over the shoe for the next cycle.

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Field Performance of Mini-Plug Transplants[1]

Y. Tanaka,[2] B. Carrier,[3] A. Dobkowski,[4] P. Figueroa,[2] and R. Meade[2]

Abstract.--A new stock type, mini-plug™ transplant (MPT), has been developed at Weyerhaeuser Company. MPT's are started in the greenhouse and transplanted into the nursery where they are grown for one season. Advantages of using MPT's are (1) short production time to improve flexibility of regeneration planning, (2) ease of planting due to compact mop-like root system and (3) relatively low production costs. A total of 68 trials to evaluate Douglas-fir MPT's were installed at six regions in Washington and Oregon in 1985, 1986 and 1987. Survival, vigor, damage and height growth were measured annually. The results showed that probably owing to favorable root to shoot ratio and fibrous roots, MPT's performed as well as or better than other bareroot stock types including 2+0's, low density 2+0's, 1+1's, plug+1's and 2+1's at a majority of sites. MPT's put on the same amount of height growth or greater than the other stock types. Furthermore, MPT's appreciably exceeded the other stock types on a relative growth rate based on the original height. However, MPT's had less total height than other stock types due to its smaller initial height. There appeared to be no preference of MPT's over other stock types in terms of frequency of big-game browsing and rabbit clipping. But, because of their smaller size, MPT's were unable to withstand heavy animal damage as well as larger stock types.

INTRODUCTION

A new method of producing planting stock called "mini-plug™ transplant (MPT)" has been adapted from the agricultural transplant industry for forestry by Steve Hee and his nursery staff, Weyerhaeuser Timberland Division (Hee, et al., 1988). Mini-plug™ starter crops are sown in December into trays with cavities about one cubic inch in volume. They are grown for 5-6 months in the greenhouse under an extended daylength. Actively growing starter plants, 4-5 inches in height, are then transplanted into the nursery beds by machine around May and grown for one season before outplanting.

There are a number of advantages to using MPT's. First, they take only one year to grow and thus increase flexibility of regeneration planning. Second, they are potentially inexpensive as compared with other types of transplants including 1+1's, 2+1's and plug+1's because of short production time, greater growing density and a high degree of mechanization. Third, they have a compact fibrous root system and are easy to plant in the field.

To determine the field performance potential of Douglas-fir MPT's, we installed a total of 68 field trials at six geographic regions in Washington and Oregon and have been monitoring their performance in comparison with other stock types in these trials annually. The present paper reports our observations to date.

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[1]Paper presented at the 1988 Western Nursery Council at Vernon, British Columbia, August 8-11, 1988.

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MATERIALS AND METHODS

Field performance of MPT's was compared with that of 2+0's, low density 2+0's, plug+1's, 1+1's and 2+1's of Douglas-fir at the following six Weyerhaeuser western regions: Cascade, Chehalis, Twin Harbors, Longview regions in Washington and Springfield and Coos Bay regions in Oregon. At each region, three types of trials were installed: (1) stock comparison tests (SCT), (2) field performance trials (FPT) and (3) region block plantings (RBP).

All the stock used in this study were produced at one of three Weyerhaeuser barreoot nurseries: Aurora located near Portland, Oregon; Mima near Olympia, Washington; and Turner near Salem, Oregon. MPT starter plants were grown at the Company's greenhouse in Rochester, Washington and subsequently transplanted into the nursery beds at Aurora and Mima. In the 1985 trials, MPT's and 2+0's stock were from both Aurora and Mima while 1+1's and 2+1's stock were from Aurora and Mima, respectively. In the 1986 and 1987 trials, all the stock tested at the Washington regions were from Mima while those tested at the Oregon regions were from Aurora. The only exceptions were the stock outplanted at the Longview region in 1986, when MPT's were from Aurora, 2+1's from Aurora (SCT) and Turner (FPT's and RBP), 1+1's from Aurora and 2+0's from Mima.

The SCT was a replicated row planting of several stock types and followed a randomized block design. It consisted of 100 trees/stock type (four blocks x 25 trees in 1985 trials and five blocks x 20 trees in 1986 trials). The approximate distance between rows was three feet and distance between trees within a row was two feet. All the stock types operationally used at a given region were included in the SCT at that region so the number of stock types varied from one region to the other. The SCT was enclosed by a fence and was protected from animal damage pressure in order to study maximum survival and growth potential. The fence was specially installed for the 1985 SCT's while progeny test sites with existing fences were used for the 1986 SCT's.

The FPT was also a replicated row planting with the same spacing between rows and trees within a row as SCT. It was a completely randomized design with four blocks each with 25 trees for a total of 100 trees/stock type. The two major differences between SCT and FPT were that (1) the FPT was not enclosed by a fence and was subject to animal damage pressure and (2) the FPT generally compared the performance of MPT's with that of one or two other stock types operationally used at the site where the FPT was located.

The RBP was a larger scale trial consisting of two 3-6 acre blocks. One block represented MPT's and the second block the other stock type operationally used in that area. Trees were planted with operational spacing of 10 x 10 feet. The trial was replicated two to three times in the 1987 installations in Chehalis, Twin Harbors and Longview. Special emphasis was placed in selection of sites so that two stock types were tested under uniform environments.

We installed a total of 68 trials during the 1985, 1986 and 1987 period. A breakdown of installations by types of trials at each region is shown in Table 1. A breakdown is also shown according to the year of installation in Table 2. Study sites used for these trials are shown in Table 3 by region and year of installation. The names of sites are accompanied by the method of site preparation in parenthesis -- burned (B), scarified (S) or no site preparation (N).

All the trials were installed at the beginning of each installation year and trees were assessed for vigor, survival, type and location of damage and height in the fall of each year following installation. Vigor, survival and damage were also assessed in early summer in many of the trials. Assessments were made on all the trees in SCT's and FPT's. In RBP's, permanent transects encompassing all areas of blocks were established and about 100 tagged trees were monitored in each stock type.

Trees were classified into one of five vigor classes using the following Weyerhaeuser western forestry seedling assessment code.

Vigor Classes	Vigor Category	Description
1	High	Green needles, no loss of foliage
2	High	Green needles, 75%+ foliage retention
3	Medium	Some chlorosis, 50%+ foliage retention
4	Low	Chlorotic, dying
5	Dead	Brown stem and foliage

Table 1.--Number of trials installed in each of three trial types at six regions in Washington and Oregon.

Region	SCT[1]	FPT[2]	RBP[3]	Total
Cascade	1	6	6	13
Chehalis	1	4	5	10
Twin Harbors	1	4	6	11
Longview	2	6	3	11
Springfield	4	10	0	14
Coos Bay	1	8	0	9

[1] Stock comparison test.

[2] Field performance trial.

[3] Region block planting.

Table 2.--Number of trials installed in each of three years at six regions in Washington and Oregon.

Region	1985	1986	1987	Total
Cascade	1	9	3	13
Chehalis	0	7	3	10
Twin Harbors	0	8	3	11
Longview	1	6	4	11
Springfield	2	6	6	14
Coos Bay	0	5	4	9
Total	4	41	23	68

Table 3.--Study sites used for MPT trials at 6 regions in 1985-1987.

Region	Year of Installation	Sites
Cascade	1985	Bald Hills (B)[1]
"	1986	Boyles Lake (N), Carnation (N), Deer Creek (S), Bayne Junction (N)
"	"	Orting Lake (N), Bald Hills (B), 3950 Road (N)
"	"	Kings Lake (N), Rhodes Lake (N)
"	1987	Barr Hill (N), Highrock (N), Greenwater (N)
Chehalis	1986	Garrard Creek (S), Bloomquist (B), Deer Creek (B and N)
"	1987	Ceres Hill (N), Deer Creek (B and N)
Twin Harbors	1986	Church Road (B), Wishkaw (N), Mayors Brother (B) Delezenne (B), Fall River (N)
"	1987	Satsop (B), Hippi Camp (N), Wiekswood (B)
Longview	1985	Mt. Brynion (B)
"	1986	Finkas (B), 1390 Road (N), 4534 Road (N), 0020 Road (B), 0518 Road (B), Tower Road (B)
"	1987	4830 Road (B), 1890 Road (B), Sucker Creek (S)
Springfield	1985	5330 Road (B), 5540 Road (B)
"	1986	Wendling (S), Shoestring (S), 3330 Road (B) 5180 Road (S), 114 Road (N), 9300 Road (B)
"	1987	7010 Road (N), 1060 Road (S), 6260 Road (B), 410 Road (B), 2340 Road (B), 5305 Road (N)
Coos Bay	1986	3394 Road (S), 8300 Road (N), 8312 Road (S)
"	1987	9120 Road (S), 9100 Road (N), 3360 Road (N), 3367 Road (N)

[1] Notations between parenthesis show methods of site preparation:

(B) - Burning (S) - Scarification (N) - None

The data was analyzed using analyses of variance procedure (Steel and Torrie, 1960). Percentage values were transformed into arcsin $\sqrt{\%}$ prior to analyses. In comparing three or more stock types, if F values were significant at the 5% risk level, the treatment differences were tested using Duncan's new multiple range test.

Because of a large amount of data from all the assessments, in the present paper we'll be only reporting selected pertinent information predominantly from the fall 1987 assessment, focusing on total survival, percent of trees with high and medium vigors and animal damage of all trials. Yearly changes of total height in 1985 and 1986 SCT are also reported.

RESULTS

Survival and Vigor

1985 Trial:

MPT's from Mima and Aurora exhibited excellent survival, 96% and 94%, respectively at Mt. Brynion, Longview after three growing seasons in the field (Table 4). Survival of Mima MPT's was significantly higher than that of 2+0's from Mima (78%) and Aurora (83%). The 2+1's from Mima showed an intermediate survival of 87%.

Table 4.--Survival of four stock types after three growing seasons in 1985 trials at four sites.

Stock Type	Nursery	Mt. Brynion[1]	Bald Hills[2]	5330 Road[3]	5540 Road[3]
MPT	Mima	96 a[4]	73 a	79 a	70 a
MPT	Aurora	94 ab	75 a	80 a	65 b
2+0	Mima	78 b	35 b	-	-
2+0	Aurora	83 b	56 ab	-	-
2+1	Mima	87 ab	31 b	-	-
1+1	Aurora	-	-	81 a	96 a

[1] Longview region, assessed in the fall of 1987.

[2] Cascade region, assessed in the fall of 1987.

[3] Springfield region, survival after two growing seasons assessed in the fall of 1986.

[4] Means followed by the same letters within each column are not significantly (p < .05) different.

At Bald Hills, Cascade, overall survival was lower than at Mt. Brynion due to harsh conditions of southern exposure and shallow soils. The survival trend, however, was the same as Mt. Brynion with MPT's from Mima (73%) and Aurora (75%) outperforming 2+0's from Mima (35%) and Aurora (56%) and 2+1's from Mima (31%).

At 5330 Road, Springfield where the field condition was also harsh (southern exposure) overall survival was also lower than at Mt. Brynion. MPT's from Mima (79%) and Aurora (80%) showed a similar level of survival as did 1+1's from Aurora (81%).

At 5540 Road, a milder site with northern exposure, survival of MPT from Mima (70%) and Aurora (65%) was greatly reduced as compared with 1+1's (96%). The survival difference was significant between Aurora MPT's and 1+1's. The reduction was mainly due to browsing by a deer which had entered the fenced area, becoming trapped and causing damage for an extended period of time. The larger 1+1's were able to withstand the browsing more than the MPT's.

1986 Trial:

<u>Cascade</u> -- MPT's performed as well as 2+1's, low density 2+0's, plug+1's and 2+1's at all FPT's except at Bayne Junction (Figure 1). Percent of MPT's with high and medium vigor was substantially reduced at this site due to rabbit clipping in the first year and big-game browsing in the second year.

As in the 1985 trial, survival of MPT's (76%) and 2+0's (68%) stock was substantially lower at Bald Hills due to harsh conditions. Although not significant, percent of trees with high and medium vigor was greater for MPT's (72%) than for 2+0's (53%).

In RBP's, survival of MPT's was significantly higher than that of 2+0's (99% vs. 85%) and low density 2+0's stock (96% vs. 87%) at Rhodes Lake and Kings Lake, respectively. At 3950 Road, both MPT's (97%) and plug+1's (94%) showed an equally high survival.

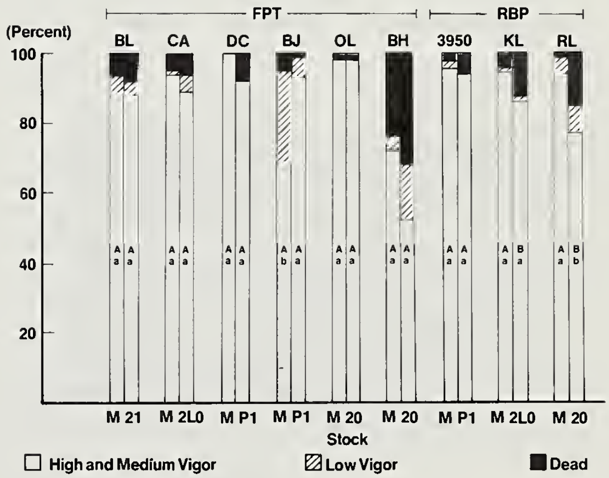

Figure 1.--Survival and vigor of mini-plug™ transplant (M) compared with those of low density 2+0 (2LO), plug+1 (P1) or 2+0 (20) in 1986 trials after two growing seasons at Cascade region, Washington: BL = Boyles Lake, CA = Carnation, DC = Deer Creek, BJ = Bayne Junction, OL = Orting Lake, BH = Bald Hills, 3950 = 3950 Road, KL = Kings Lake, RL = Rhodes Lake. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and high and medium vigor (small letter).

Chehalis -- In SCT's and FPT's, MPT's showed high survival rates of over 90% and did as well as 2+0's, 2+1's, 1+1's or plug+1's at all sites (Figure 2). In the RBP's, plug+1's survived significantly better than MPT's (96% vs. 82%) at Deer Creek burned site while an opposite trend was observed at Deer Creek which received no site prep. (82% vs. 89%, not significant).

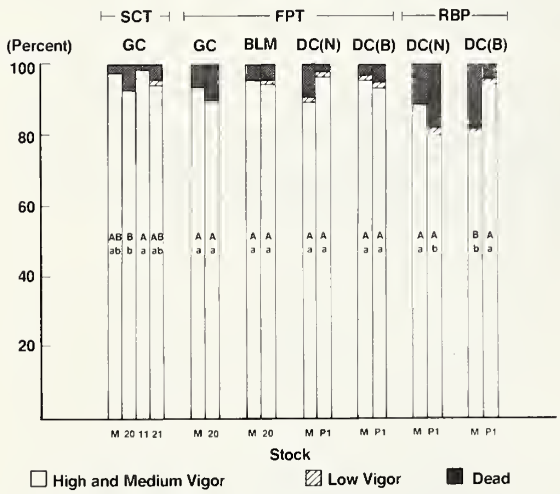

Figure 2.--Survival and vigor of mini-plug™ transplant (M) compared with those of 2+0 (20), 1+1 (11), 2+1 (21) or plug+1 (P1) in 1986 trials after two growing seasons at Chehalis region, Washington: GC = Garrard Creek, BLM = Bloomquist, DC(N) = Deer Creek, no site preparation, DC(B) = Deer Creek, burned. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and in high and medium vigor (small letter).

Twin Harbors -- Survival of MPT's and plug+1's was substantially reduced (to less than 75%) at Delezenne FPT and RBP (Figure 3). Although the difference in survival or percent of trees with high and medium vigor was not significant, the impact of the damage tended to be greater for the smaller MPT's. Survival of MPT's was also significantly reduced by big-game browsing as compared with 2+0's (61% vs 91%) at Fall River RBP. MPT's performed equally well or better than other stock types where animal damage pressure was low.

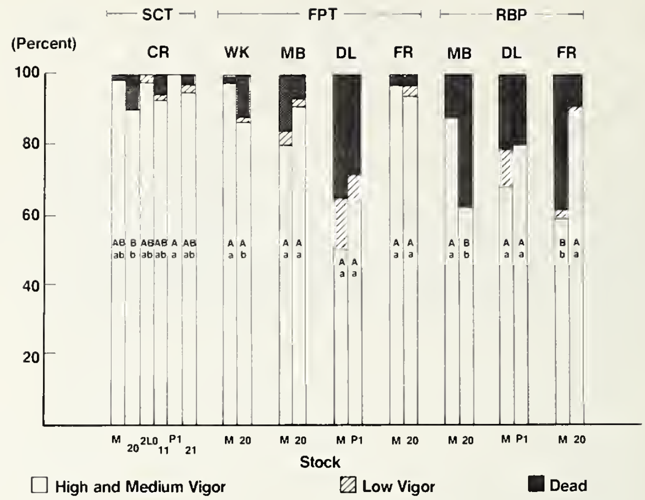

Figure 3.--Survival and vigor of mini-plug™ transplant (M) compared with those of 2+0 (20), low density 2+0 (2LO), 1+1 (11), plug+1 (P1) or 2+1 (21) in 1986 trials after two growing seasons at Twin Harbors region, Washington: CR = Church Road, WK = Wishkaw, MB = Mayor Brother, DL = Delezenne, FR = Fall River. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and high and medium vigor (small letter).

Longview -- MPT's generally had lower survival (75%-87%) at this region than at Cascade, Chehalis and Twin Harbors (Figure 4). Poorer performance is attributed to unusually severe winter damage from freezing and desiccation while in the nursery beds at Aurora. Many lots of transplants from Aurora showed less than normal survival in 1986. In contrast, 2+1's stock from Turner, which did not suffer winter injury, showed high survival rates of mostly over 90%. The difference between survival of MPT's and 2+1's was significant at 1390 Road FPT (95% vs 77%) and at 4534 Road FPT (95% vs. 75%). At Finkas SCT, however, MPT's survived as well as 2+1's or 1+1's from the same nursery. Damage caused by big-game browsing significantly reduced the percent of trees with high and medium vigor as compared with 2+1's (29% vs. 85%) at Tower Road RBP.

Oregon -- As in Longview, overall survival of MPT's, 1+1's and 2+0's stock was relatively low and variable at Springfield (Figure 5) and at Coos Bay (Figure 6) due to the winter nursery damage. MPT's survived as well as 1+1's and 2+0's stock at eight out of 11 trials in these regions.

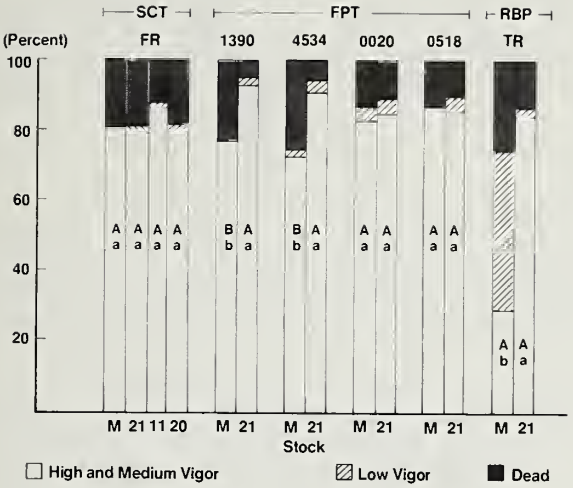

Figure 4.--Survival and vigor of mini-plug™ transplant (M) compared with those of 2+1 (21), 1+1 (11), or 2+0 (20) in 1986 trials after two growing seasons at Longview region, Washington: FR = Finkas road, 1390 = 1390 Road, 4534 = 4534 Road, 0020 = 0020 Road, 0518 = 0518 Road, TR = Tower Road. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and high and medium vigor (small letter).

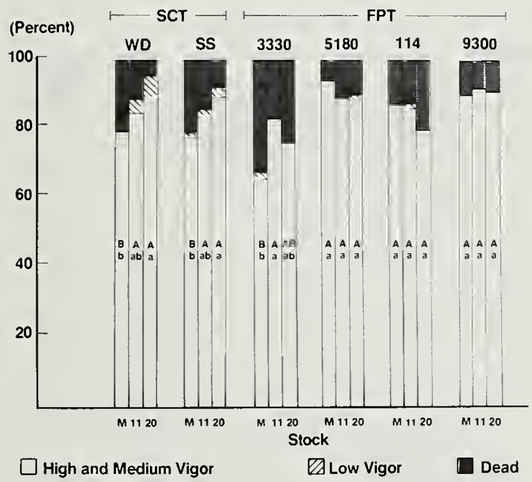

Figure 5.--Survival and vigor of mini-plug™ transplant (M) compared with 1+1 (11) or 2+0 (20) in 1986 trials after two growing seasons at Springfield region, Oregon: WD = Wendling, SS = Shoestring, 3330 = 3330 Road, 5180 = 5180 Road, 114 = 114 Road, 9300 = 9300 Road. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and high and medium vigor (small letter).

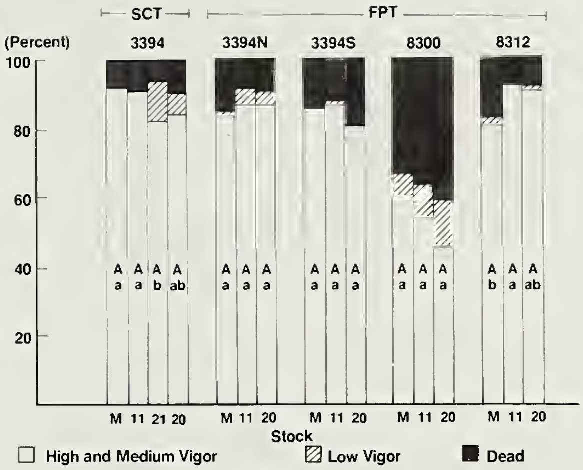

Figure 6.--Survival and vigor of mini-plug™ transplant (M) compared with those of 1+1 (11), 2+1 (21), or 2+0 (20) in 1986 trials after two growing seasons at Coos Bay region, Oregon: 3394S = 3394 Road south-facing slope, 8300 = 8300 Road, 8312 = 8312 Road. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and high and medium vigor (small letter).

1987 Trial:

Cascade -- MPT's performed as well as 1+1's stock at Barr Hill and Greenwater and slightly better than low density 2+0's stock at Highrock (Figure 7).

Chehalis and Twin Harbors -- The frequency of animal damage was relatively high at most sites (30% - 70%). However, browsing and clipping were mostly on lateral branches and generally had no significant impact on survival after one growing season. MPT's did as well as 2+0's, 1+1's and 2+1's stock at all sites except at Deer Creek (with no site prep.) where 1+1's survived significantly better than MPT's (100% vs. 95%). (Figure 8)

Longview -- MPT's and 1+1's showed an excellent performance of survival over 95% in both FPT's and RBP's at all three sites (Figure 9). At Sucker Creek RBP, survival of MPT's was reduced to 79% as compared with 2+1's (92%) due to rabbit clipping; however, the difference was not significant because of the large variability within stock types.

Springfield -- All three stock types including MPT's, 1+1's and plug+1's showed excellent performance at all six FPT's sites in Springfield with survival exceeding 95% (Figure 10).

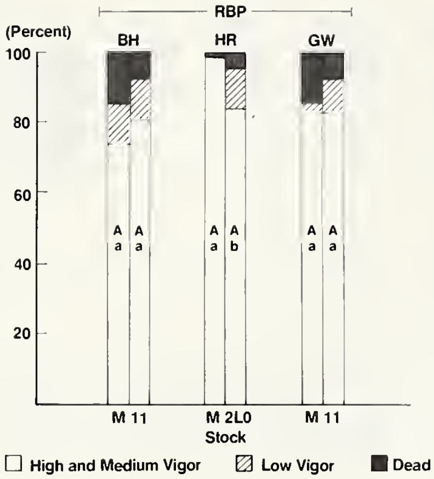

Figure 7.--Survival and vigor of mini-plug™ transplant (M) compared with those of 1+1 (11), or 2+0 (20) low density 2+0 (2LO) in 1987 trials after one growing season at Cascade region, Washington: BH = Barr Hill, HR = Highrock, GW = Greenwater. Within each site, stock types followed by the same letters are not significantly (p<.05) different in total survival (capital) and high and medium vigor (small letter).

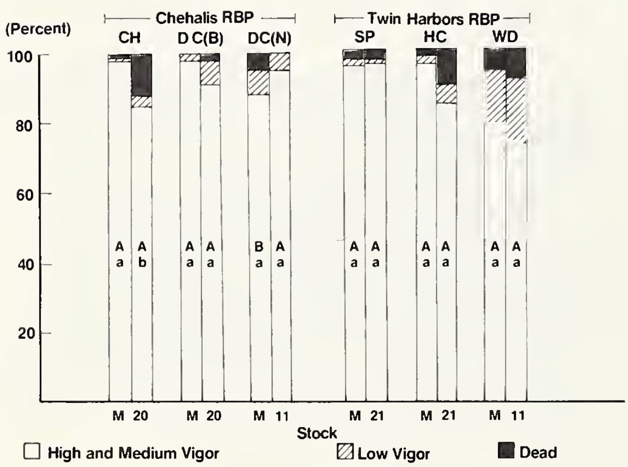

Figure 8.--Survival and vigor of mini-plug™ transplant (M) compared with 2+0(20), 1+1(11) or 2+1(21) in 1987 trials after one growing season at Chehalis and Twin Harbors regions, Washington: CH = Ceres Hill, DC(B) = Deer Creek burned site, DC(N) = Deer Creek no site preparation, SP = Satsop, HC = Hippi Camp, WD = Wiekswood. Within each site stock types followed by the same letters are not significantly (p < .05) different in total survival (capital) and high and medium vigor (small letter).

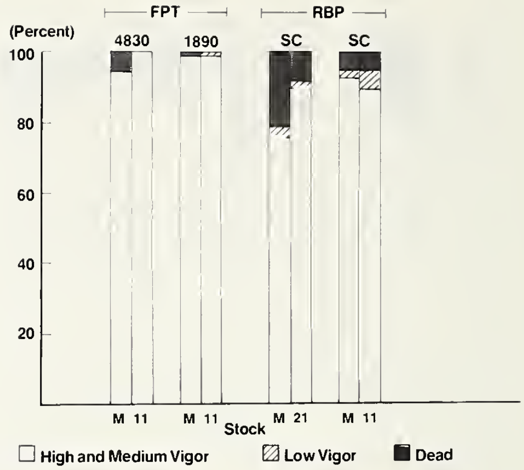

Figure 9.--Survival and vigor of mini-plug™ transplant(M) compared with those of 1+1(11) or 2+1(21) in 1987 trials after one growing season at Longview region, Washington: 4830 = 4830 Road, 1890 = 1890 Road, SC = Sucker Creek. Within each site, the differences between stock types were not significant (p < .05) in total survival or in high and medium vigor.

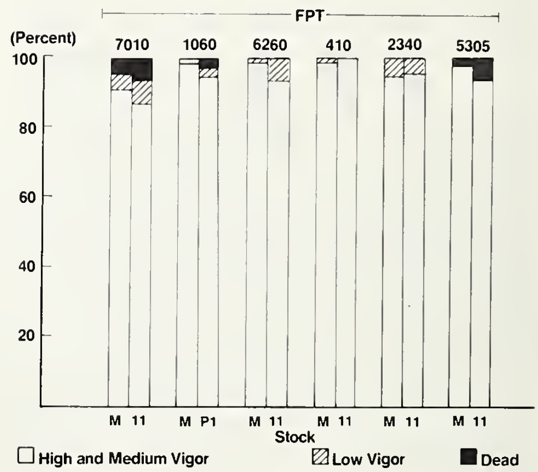

Figure 10.--Survival and vigor of mini-plug™ transplant(M) compared with those of 1+1(11) or plug+1(p1) in 1987 trials after one growing season at Springfield region, Oregon: 7010 = 7010 Road, 1060 = 1060 Road, 6260 = 6260 Road, 410 = 410 Road, 2340 = 2340 Road, 5305 = 5305 Road. Within each site, the differences between stock types were not significant (p < .05) in total survival or high and medium vigor.

Coos Bay -- Overall survival was somewhat lower at Coos Bay than at Springfield (Figure 11). The 1+1's tended to perform slightly better than MPT's and 2+0's, but the differences among stock types were not significant.

HEIGHT GROWTH

Height growth of MPT's paralleled that of 2+0's and 2+1's at Mt. Brynion 1985 SCT site (Figure 12). After three growing seasons in the field, the height differences among three stock types were about the same as those at the time of outplanting.

The observations from 1986 SCT's showed that the height growth rate of MPT's was greater than that of 2+0's with both stock types attaining the same total height (73 cm) after two growing seasons in the field, although the original height of 2+0's (30 cm) was greater than that of MPT's (19 cm) (Figure 13). A similar trend was also observed in the 1986 FPT's and RBP's (unpublished data).

The 1986 SCT's also showed that the total height after two growing seasons was greater for 2+1's (92 cm) and 1+1's (91 cm) than for MPT's. But the growth rate of MPT's was the same or slightly greater than those of 2+1's or 1+1's as evidenced by slightly smaller differences in total height between stock types after two growing seasons.

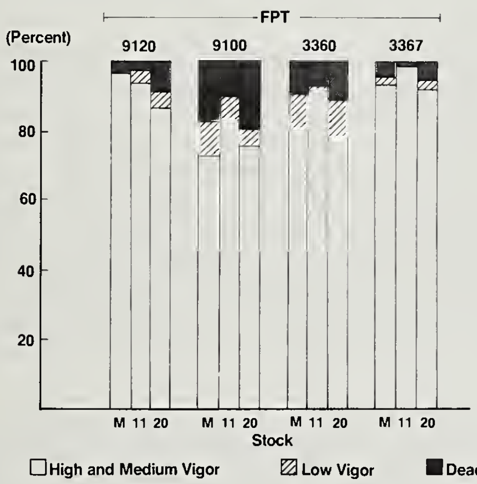

Figure 11.--Survival and vigor of mini-plug™ transplant(M) compared with those of 1+1(11) or 2+0(20) in 1987 trials after one growing season at Coos Bay region, Oregon: 9120 = 9120 Road, 9100 = 9100 Road, 3360 = 3360 Road, 3367 = 3367 Road. Within each site, the differences between stock types were not significantly ($p < .05$) different in total survival or high and medium vigor.

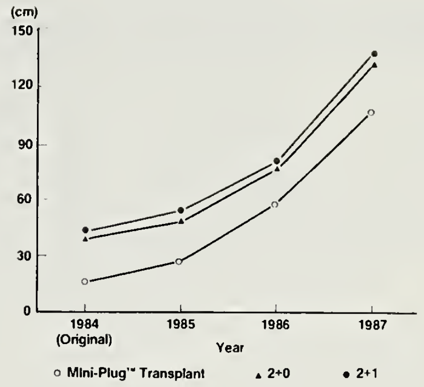

Figure 12.--Total height of three stock types at Mt. Brynion, Longview. All measurements were done in the fall of each year.

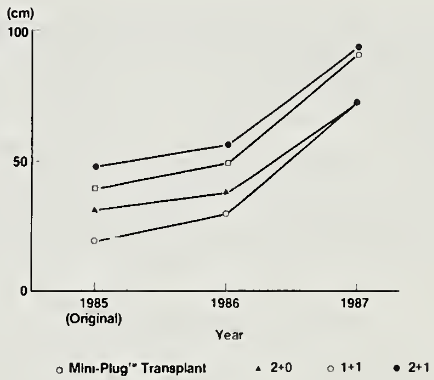

Figure 13.--Total height of three stock types. Mean of three stock comparison tests installed in 1986. All measurements were done in the fall of each year.

ANIMAL DAMAGE

The above survival and vigor data showed that the impact of animal damage was greater on MPT's than on other stock types due to their smaller original size. There was no distinct preference of MPT's over other stock types based on the frequency of animal damage in 1986 (Table 5) and 1987 (Table 6) trials, the browsing just caused more damage to the smaller MPT's.

With respect to site preparation, animal damage of MPT's tended to be greater on burned sites than on scarified sites or sites with no preparation in both 1986 (Table 7) and 1987 (Table 8) trials.

Table 5.--Percent of animal-damaged trees by stock type during the first (1986) and second (1987) year after outplanting in 1986 FPT and RBP.

STOCK TYPE	FPT 86 (%)	FPT 87 (%)	RBP 86 (%)	RBP 87 (%)
MPT	12	17	38	21
2+0	6	16	17	18
1+1	6	21	-	-
2+1	28	20	12	-
P+1	18	25	22	12

Table 6.--Percent of animal-damaged trees by stock type during the first (1987) year after outplanting in 1987 FPT and RBP.

STOCK TYPE	FPT (%)	RBP (%)
MPT	13	25
2+0	11	12
1+1	15	15
2+1	-	42
P+1	28	65

Table 7.--Percent of animal-damaged trees by site preparation during the first (1986) and second (1987) year after outplanting in 1986 FPT and RBP.

SITE PREP	FPT 86 (%)	FPT 87 (%)	RBP 86 (%)	RBP 87 (%)
BURN	31	20	44	29
SCARIFIED	6	15	-	-
NONE	7	10	28	16

Table 8.--Percent of animal-damaged trees by site preparation during the first (1987) year after outplanting in 1987 FPT and RBP.

STOCK TYPE	FPT (%)	RBP (%)
BURN	20	42
SCARIFIED	1	-
NONE	10	8

DISCUSSION

Based on survival, vigor and height growth, MPT's performed as well as or better than other bareroot stock types including 2+0's, low density 2+0's, 1+1's, plug+1's and 2+1's at a majority of sites. Superior performance of MPT's was particularly evident at a shallow, harsh site at Bald Hills, Cascade Washington, where larger 2+0's and 2+1's stock showed lower survival rates. It was also noted that MPT's do not appear to suffer from transplant shock as much as other stock types as was evidenced by their generally comparable or superior height growth over the other larger stock types. In terms of the percent of the original height, height growth of MPT's was significantly greater than that of other stock types.

Good survival and height growth of MPT's are attributed to their morphological characteristics. They have a high root to shoot (R/S) dry weight ratio and fibrous root system. Measurements of stock outplanted in 1987 showed that R/S ratio of MPT's (0.62) was greater than that of 2+0's (0.38), 1+1's (0.38), 2+1's (0.42) or plug+1's (0.47) (Table 9). The MPT's are also characterized by a mop-type fibrous root system which results from many growing tips created by air-pruning of roots near the root collar while growing in the containers (Hee et al 1988).

Use of MPT's increases flexibility of reforestation planning because of their short production time of one year. Changes in logging schedules or an unexpected fire could create a need for a readily available planting stock such as MPT's. MPT's are also less costly to produce than 2+1's or plug+1's, although their production costs are currently similar to that of 1+1 because of a somewhat variable yield. We expect, however, that the cost of MPT's will be less than that of 1+1's in the near future because they require a short production time, transplanting is highly mechanized and they are grown at a higher density.

Table 9. Morphological characteristics of five stock types used in 1987 installation.

Stock type	Avg. Height	Avg. Diameter	Dry Weight Shoot	Root	R/S ratio
	(cm)	(mm)	(g)	(g)	
MPT	23	4.7	3.8	2.3	0.62
2+0	38	5.1	5.5	2.0	0.38
1+1	46	6.7	11.4	4.3	0.38
2+1	54	7.8	15.8	6.6	0.42
P+1	40	6.1	8.2	3.3	0.47

While height growth in percentage of original height was the greatest of all stock types, total height of MPT's at the end of the first, second and third year in the field was generally smaller than that of other stock types due to their smaller original size. Because of this factor, MPT's were often unable to withstand big-game browsing and rabbit clipping as well as the larger stock types especially if damage occurred prior to budbreak. Survival, vigor and growth of MPT's were significantly reduced in areas of heavy animal pressure in Twin Harbors and Longview in 1986. Further observations suggested, however, that there was no preference of MPT's over other stock types based on the frequency of animal damage.

In order to minimize such animal damage, it appears to be advantageous to use larger MPT's than the ones currently produced without compromising the root to shoot balance and fibrosity of roots. Nursery trials have been in progress with promising results. Crops started in mid-summer and subsequently (1) transplanted in fall or (2) stored in a cooler or freezer before transplanting the next May have shown larger and more uniform size than the current crop. This crop requires an additional half-year to produce but may perhaps be more desirable for use in the areas with heavy animal damage pressure.

It has been pointed out that tree planters have difficulty in maintaining spacing between trees in the field due to poor visibility of small MPT's. However, this advantage may be offset by the fact that the root system of MPT's is compact and easy to plant. This seems to be particularly true in poorly prepared sites or rocky sites where stock with a larger root system is difficult or sometimes impossible to plant.

The present study indicated that the frequency of animal damage of MPT's was greater in burned areas than in areas with no site preparation. Additional observations from specifically designed trials would be needed to ascertain this trend since the present study was not intended to test the differences of site preparation under similar field conditions. The observations, however, are in agreement with those of others (Campbell 1982). If the above trend is proven to be true it may be possible to reduce the level of animal damage by planting MPT's in areas with minimum site preparation.

ACKNOWLEDGEMENTS

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Computer Vision for Grading Tree Seedlings[1]

Michael P. Rigney and Glenn A. Kranzler[2]

A computer vision algorithm measuring several morphological characteristics of pine seedlings was developed. Singulated seedlings were inspected on a moving belt at production-line rates. Classification as acceptable or cull was based on minimum criteria for stem diameter, shoot height, and projected root area. Individual seedlings were graded in approximately 0.25 seconds. Average classification error rate was 5.7 percent.

INTRODUCTION

Hundreds of millions of tree seedlings are grown annually in commercial, federal, and state nurseries. At harvest, these seedlings are graded to remove inferior stock and improve productive potential. Advances in equipment and cultural practices leave seedling grading as the only remaining labor-intensive operation at most nurseries.

Grading is typically performed manually through application of a number of visual quality criteria. Although stock types and cultural practices vary widely among nurseries, several generalizations may be made about current grading practice. Manual inspection tends to be labor-intensive and costly. Seedling classification is subjective and susceptible to human error. Grading and sorting into multiple acceptable classes is not feasible. Valuable production data, including morphological statistics and cull rate, are difficult to obtain. Disadvantages of manual grading have spurred growing interest in automated alternatives.

Automated systems have been constructed for measurement of seedling characteristics (Buckley et al., 1978) and seedling grading (Lawyer, 1981). Mechanical and opto-electronic methods were used to successfully measure stem diameter, shoot height, and projected root area, however, neither machine could match manual grading productivity.

[1] Paper presented at the 1988 Conference of the Western Forest Nursery Council and Forest Nursery Association of British Columbia. [Vernon, B.C., August 8-11, 1988]. Paper No. 2822 of the Oklahoma Agricultural Experiment Station.

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Digital image processing has been successfully implemented in many industrial and agricultural inspection processes. It has demonstrated high accuracy and throughput, permitting 100% inspection where product sampling was previously the only feasible method of quality control (Kranzler 1985). Machine vision inspection would appear to be an ideal tool for addressing the tree seedling grading problem.

OBJECTIVES

This study was initiated to investigate the ability of machine vision to grade bare-root pine seedlings under nursery production conditions. Specific objectives included:

1. Develop and implement a machine vision algorithm to measure key morphological characteristics and grade seedlings at production-line rates.
2. Evaluate performance in terms of measurement speed, precision, and accuracy of classification.

METHODS AND MATERIALS

Assumptions

Several assumptions were adopted concerning the environment in which commercial grading would be performed. First, seedlings would be singulated, permitting only one seedling to appear within the camera field-of-view at a given time. This requirement could be relaxed to the constraint that adjacent seedlings simply must not touch. Singulation is straightforward for container-grown seedlings, but bare-root stock requires special handling equipment (Graham and Rohrbach, 1983).

Second, loose constraint of shoot orientation (+/- 30 degrees) and lateral position (+/- 6 cm) was imposed. Orientation and position constraints simplify both hardware and software, but are not necessary for

commercial implementation. Finally, it was assumed that a black conveyor belt would be used to transport seedlings beneath the cameras. Again, other configurations are possible, for example, acquiring images as the seedlings fall past a backlight.

Equipment

Equipment included a conveyor belt, machine vision computer, cameras, lenses, and lights. To simulate production grading operations, a variable-speed belt conveyor was constructed to transport seedlings for inspection. The shiny surface of the black belt was dulled by sanding to minimize specular reflection.

An International Robomation/Intelligence (IRI) D256 machine vision development system was used. Images were digitized into an array of 256 X 240 picture elements (pixels) with 256 grey levels of intensity. A high-speed hardware coprocessor performed computationally intensive operations such as image windowing, filtering and edge detection, runlength-encoding, and moments calculations. Software was developed in the C programming language.

Two Hitachi KP-120U solid-state black-and-white television cameras were employed for image acquisition. Camera 1 was used to obtain a close-up image of the seedling root collar zone. A field-of-view (FOV) approximately 12.8 cm (5 in) square provided a 0.5 mm (0.02 in) pixel resolution (fig.1). Camera 2, with a FOV approximately 51 cm (20 in) square and resolution of 2.2 mm, acquired an image of the entire seedling.

Illumination was provided by fluorescent room lighting and strobed xenon flash. Relatively low-level room lighting was adequate for detection of the moving seedlings in the FOV of camera 2. When a seedling was detected, synchronized strobe lamps were triggered to obtain a "frozen" image with each camera.

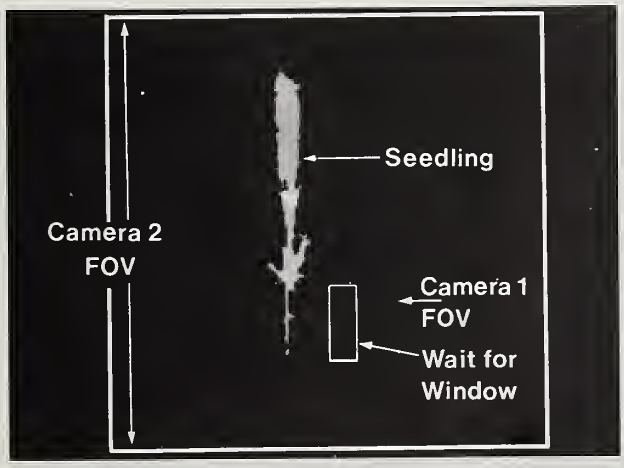

Figure 1.--Field-of-view for cameras 1 and 2. Note Waitfor window.

Grading Scheme

Morphological characteristics are used for grading most nursery stock. These characteristics include stem diameter at the root collar, shoot height and weight, root weight or volume, root fibrosity, foliage color, presence of terminal buds, shoot/root volume ratio, and ratio of top height to stem diameter (sturdiness ratio) (Forward 1982, May et al. 1982). Stem diameter, shoot height, and root volume are generally given priority and were adopted as the grading criteria for this study. Of these three, stem diameter is typically considered most important.

To meet image processing time constraints, we decided to emphasize stem diameter measurement accuracy and obtain close approximations of shoot height and of root volume as indicated by projected root area (root area index). A classification scheme based on minimum acceptable values of these three parameters (May et al. 1982) is given in table 1. Seedlings were graded into two classes; acceptable and cull.

ALGORITHM

The grading algorithm is composed of several separate tasks. These are: calibration, seedling detection, shoot orientation measurement, root collar location, diameter measurement, root area measurement, shoot height measurement, grade classification, and recording of seedling statistics. A detailed description of the algorithm is presented by Rigney (1986).

Selection of FOV for camera 1 required a compromise between diameter measurement precision and the probability of the root collar appearing within the FOV. Because the lateral position of the root collar cannot be tightly constrained, a relatively wide FOV is necessary. We decided to make the FOV as large as possible, while maintaining a measurement precision of at least 0.5 mm (0.02 in). Selecting 0.5 mm as the pixel resolution yields a 12.8 cm FOV. Measurement precision can be increased through use of a smaller FOV and more precise seedling handling or by substituting a higher resolution camera/computer system.

Seedling Detection

Under ambient lighting conditions, a sequence of images acquired with camera 2 (wide FOV) is processed as follows. Each image is masked by a template defining a window in which seedling presence is tested (Waitfor window, fig. 1). Seedling detection triggers image acquisition from each camera with strobe illumination. In the following algorithm descriptions, image 1 and image 2 refer to images acquired by camera 1 and camera 2, respectively.

Seedling Orientation

Image 2 is first processed to determine seedling orientation on the conveyor belt. Area moment calculations provide the angle between the seedling major axis and the vertical axis of figure 1.

Table 1.--Grading scheme for loblolly pine seedlings

Stem Diameter (mm)	Root Area Index (pixels)	Shoot Height (cm)	Grade
3.0 to 8.0	> 200	> 16	Acceptable
Otherwise			Cull

Subsequent measurements of stem diameter and shoot height are corrected for orientation angle. Because measurement error becomes excessive at large angles, seedlings are not graded if the orientation angle is greater than thirty degrees.

Location of the Root Collar

Accurate location of the root collar is crucial for subsequent measurement of stem diameter, shoot height, and root area index. Image 1 (small FOV) is processed by an iterative algorithm to find a collar location satisfying heuristic criteria. Consider each horizontal line in the image to be composed of pixel strings belonging either to the foreground (seedling) or background (conveyor). Further, define the frequency of a line to be the number of transitions between the foreground and background. The root collar may intuitively be expected to be located in a region of low frequency lines bounded by areas of higher frequency. Needles, branches, and roots contribute many transitions to horizontal lines in figures 2 and 3 (high frequency). Lines in the root collar zone contain significantly fewer transitions. The width of individual pixel strings is also exploited, since we have a priori knowledge of the expected stem width.

Line frequencies are processed to build a list of root collar candidates. The resulting list is processed to locate the root collar both vertically and horizontally. The algorithm will find the root collar of most seedlings in one iteration. Seedlings with branches, needles, or roots in the root collar zone require two iterations for collar location.

The scale and mapping relationship between images 1, and 2 was previously determined during system calibration. After locating the root collar in the close-up image 1 the collar location is mapped into image 2.

Measurement of Stem Diameter

Diameter measurement processing is performed inside a region around the root collar location in image 1. Region size is defined by the set of candidate collar lines found in the collar location subroutine. The region is processed with an edge detector favoring vertical edges, since we know that shoot orientation is approximately vertical. An edge detection operation yields an image of edge intensity. The average distance between the strongest edges bracketing the root collar is calculated as the collar diameter (fig. 4).

Figure 2.--Camera 1 close-up image details root collar region.

Figure 3.--Algorithm locates root collar.

Measurement of Root Area Index

Root area index is measured from that portion of image 2 below the root collar (as mapped from image 1). An edge detector sensitive to all edge orientations is applied. The weakest edges detected are the result of noise in the image background (conveyor belt). Above the noise level, however, roots much smaller than the pixel dimension (2.2 mm) can be detected because of their contribution to the brightness of a corresponding pixel. Pixels with edge intensities greater than the noise level are summed to yield projected root area (fig. 5).

Measurement of Shoot Height

Image 2 is processed to determine shoot height. Starting at the top of the image, each line is tested to determine if it has enough information to indicate the presence of the seedling top. The seedling top is assumed to be located when four consecutive lines meet this criterion. Shoot height is defined as the distance between the seedling top and root collar (previously mapped into image 2).

Measurement of Shoot Area

Projected shoot area is determined from that portion of image 2 above the root collar. Pixels with an intensity greater than the background intensity are counted to provide area. This measurement was amended to those described above to allow calculation of shoot/root area ratio.

Main Program

Inside the main program loop, values returned by subroutines are tested to control program flow. If all grading subroutines are successful in their respective tasks, a grade classification is assigned to the seedling.

Whenever a subroutine fails its task, the seedling is recorded as not gradable. Finally, measured seedling parameters, grade, and count are written to a statistics file.

Calibration

Proper calibration of threshold values and scale factors is essential for optimum algorithm performance. The calibration subroutine initializes sixteen parameters with default values. The user is then provided an opportunity to interactively alter the default values. A wooden dowel of known diameter and length is used to calibrate scale factors. Grey level thresholds are set using a representative seedling. Algorithm performance was relatively insensitive to grey level thresholds if "reasonable" values were selected. Threshold selection could be automated in a commercial implementation, eliminating operator subjectivity.

EVALUATION

A reference set of 100 loblolly pine (Pinus tacda L.) seedlings was manually measured and graded. Stem diameters ranged from 2.3 to 6.0 mm. Performance of the machine vision system was then evaluated by grading each of the seedlings twenty times. Shoot orientation was limited to plus-or-minus thirty degrees from vertical, and root collar location was constrained to the FOV of camera 1.

Time required for the algorithm to grade a seedling averaged approximately 0.25 seconds. Strobe illumination provided reliable image capture at conveyor speeds of up to 1.0 m/s (3.3 ft/s), corresponding to a grading rate exceeding three seedlings per second. To facilitate manual placement of the seedlings on the conveyor, tests were conducted at a belt velocity of 0.5 m/s (1.5 ft/s).

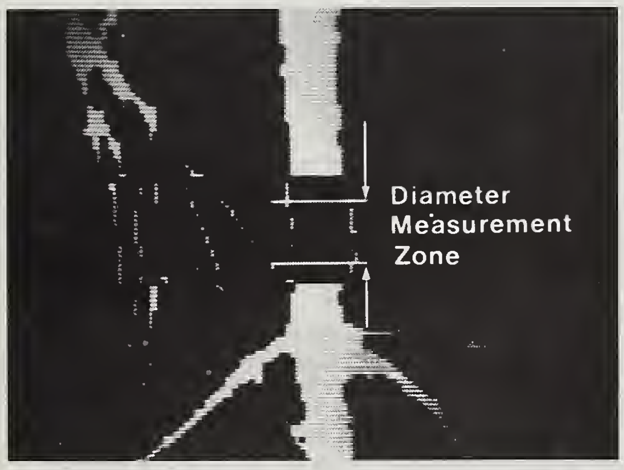

Figure 4.--Image is processed to define stem edges in root collar zone.

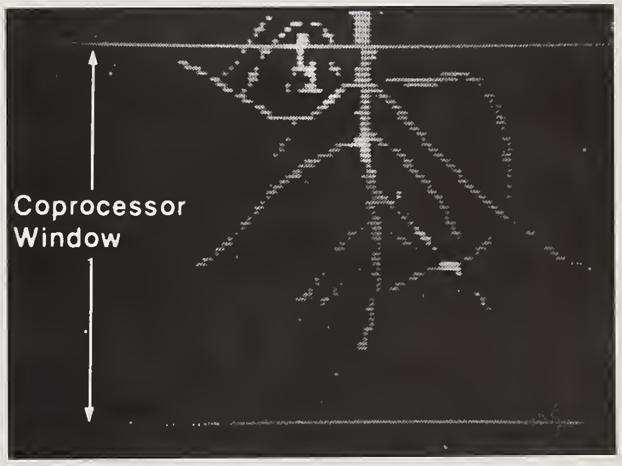

Figure 5.--Image is processed to highlight seedling roots.

Table 2.--Percent misclassification of 100 seedlings, 20 reps

Manual Grade	Acceptable		Cull		Total		
	#	mis.	#	mis.	#	mis.	n.g.
Borderline	6	31.7%	11	18.6%	17	23.2%	2.6%
Easily Classified	63	2.2%	20	2.0%	83	2.2%	2.3%
All	69	4.7%	31	7.9%	100	5.7%	2.3%

n.g. = not gradable mis. = misclassified

The classification error rate averaged 5.7 percent for the set of 100 seedlings (table 2). This is very acceptable performance, bettering manual grading operations which have an average misclassification rate of seven to ten percent (Boeckman, 1986). As expected, a large part of the classification error was attributable to seedlings which straddled the borderline between acceptable and cull, with respect to diameter and root area. Such seedlings comprised 17 percent of the grading test set and had an average misclassification rate of 23.2 percent. The remaining 83 seedlings had an average misclassification rate of 2.2 percent (table 2). Since there is no significant penalty for misclassification of borderline seedlings, 2.2 percent misclassification may be a better indicator of algorithm performance.

Measurement precision was excellent, considering the spatial resolutions of cameras 1 and 2, which were 0.5 mm/pixel and 2.2 mm/pixel respectively. The coefficient of variation of 20 measurement repetitions averaged 7.6, 12.2, and 4.1 percent for stem diameter, root area, and shoot height, respectively. This result indicates a standard deviation of 0.23 mm for a 3.0 mm stem diameter.

The few seedlings which showed the largest deviations in measured parameters were characterized either by needles extending down past the root collar, or by roots bent upward past the root collar, or both. The subroutine which located the root collar performed inconsistently on such seedlings. A few of these seedlings could not be graded.

In subsequent work, projected shoot area was measured, allowing calculation of shoot/root area ratio. Though not tested, we anticipate a correlation between projected area and mass, allowing fast and non-destructive estimation of conventional shoot/root mass ratio. Calculation of the sturdiness ratio (diameter/height) has also been implemented and could provide another parameter for classification.

The measurement precision demonstrated by the algorithm suggests use for classification of seedlings into several acceptable grades. Additional grade definitions could be optimized for specific planting sites. Further, we expect that the comprehensive statistics collected in a commercial implementation would make machine vision grading a valuable nursery management and research tool.

The research described was implemented on a 240 X 256 pixel resolution camera/computer system which was the industry standard at the time of purchase (1984). Systems with 512 X 512 pixel resolution are common today, and the trend toward increased resolution is expected to continue. New systems, with improved architectures and faster central processing units, offer an increase in measurement precision as well as reduced processing time.

The two-camera configuration used in this investigation could be replaced with a single-camera 1024 X 1024 pixel system to yield identical diameter resolution, quadruple height resolution, and 16 times the area resolution. In such a configuration, the amount of raw data (pixels) would increase by a factor of eight. A large percentage of the image would be background, however, and would not require processing.

Further work is being performed in seedling classification and measurement of container grown seedlings. Alternative decision functions, including statistical classifiers, are being investigated for improved classification performance. Plug-surface root-area measurement of container grown seedlings (after extraction) requires segmentation of the roots from the growth medium with special lighting and image processing. Verification of correct plug shape might also be of value.

SUMMARY AND CONCLUSIONS

This study has demonstrated that machine vision can provide accurate production-rate grading of harvested bare-root pine seedlings. Singulated seedlings were transported on a conveyor belt, with shoot orientation and root collar position loosely constrained. Seedlings were classified as acceptable or cull on the basis of stem diameter, shoot height, and projected root area. Tests with loblolly pine seedlings revealed excellent system performance. Seedlings were graded in approximately 0.25 seconds, with an average classification error rate of 5.7 percent. These results

exceed manual grading performance, which typically requires one second per seedling with an error rate of seven to ten percent. Misclassification was largely due to seedlings with borderline diameter and/or root area, and the occurrence of branches or roots in the root collar zone. Measurement precision was adequate for seedling classification into several grades, suitable for specific planting sites. The technology promises increases in both speed and measurement accuracy.

DISCLAIMER

Reference to commercial products or trade names is made with the understanding that no discrimination is intended or endorsement implied.

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Effect of Nursery Treatment on Shoot Length Components of Western Hemlock Seedlings during the First Year of Field Establishment[1]

Conor O'Reilly,[2] John N. Owens,[2] J.T. Arnott,[3] and B.G. Dunsworth[4]

Abstract.--The effects of nursery pretreatments, such as dormancy induction (photoperiod and moisture availability), two styroblock cavity sizes, and three dates of lifting and cold storage duration, on shoot length components were investigated in seedlings of western hemlock (Tsuga heterophylla (Raf.) Sarg.) during their first year of growth on two sites on Vancouver Island, B.C. Seedlings pretreated to short days combined with moisture stress and those lifted in November had very short shoots. Seedlings pretreated to long days and those lifted in March had the longest shoots. Because most stem units were preformed during bud development in the nursery, differences in stem unit length had a larger impact on shoot length than differences in number of stem units. Lammas growth was most frequent in seedlings from the smaller cavities and in those from the November and March lifts.

INTRODUCTION

A variety of western hemlock Tsuga heterphylla (Raf.) Sarg.) seedling stock types having different physiological and morphological characteristics can be produced by modifying nursery cultural practices (O'Reilly et al. 1989a, 1989b; Arnott et al. 1989; Grossnickle et al. 1989). A logical follow-up would be to see how different stock types perform under field conditions. To this end, we carried out a study of the phenology of flushing and shoot elongation, seedling morphology, and bud development of different seedling stock types of western hemlock growing on two adjacent sites, typical for the growing environment of the species on Vancouver Island. This paper summarizes some of the results on the effects of nursery pretreatment on shoot length components. The results of other parts of the field study will be reported elsewhere.

MATERIALS AND METHODS

Seedling Stock Types

Western hemlock seedlings of mid-elevation (British Columbia Ministry of Forests Registered Seed Lot No. 3907; 48° 39' N, 123° 39' W, elevation, 760 m) seedlot from Vancouver Island were grown in BC/CFS styroblocks (PSB) (Beaver Plastics Ltd., Edmonton, Alta.) of small (PSB 313 abbreviated to S3) and large (PSB 415B abbreviated to S4) cavity diameters that were subjected to different dormancy induction and lift/storage treatment combinations (see Arnott et al. 1989). The seedlings were grown under 18 h day lengths until the dormancy induction treatments began. The dormancy induction treatments included short- (8 h) (SD) or long-day (18 h) (LD) photoperiods in combination with drought (D = dry) or no drought (W = wet) conditions that began in mid-July, 1986 and ended 4 weeks later. Seedlings were grown under ambient day length conditions thereafter. The final treatment included three lifting dates/cold storage duration treatments that took place in mid-November, 1986 (lift N), mid-January (lift J) and mid-March (lift M) 1987, for a total of 24 nursery treatment combinations. Seedlings

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from lifts N and J were stored at 1°C in cold rooms at the Pacific Forestry Centre, Victoria until the final lift on March 18, 1987. All seedlings were transported to Nanaimo, B.C. where they were stored in a MacMillan Bloedel cold room (1°C) until planting.

Study Area

The seedlings were planted in early April, 1987 on 2 adjacent sites at the Summit Main (SR5), Franklin River Division, MacMillan Bloedel Ltd. (Lat. 48° 55' N, Long. 124° 45', elev. 675 m). This area is within the windward submontane maritime wetter CWH variant (CWHb1) as described by Green et al. (1984). One site, facing northwest (NW), is classified as wet (hygrotope 5-6, trophotope B-C (burnt)) while the other is classified as dry (hygrotope 1-2, trophotpe B-C (burnt)) and is of southeast (SE) aspect. Average slopes on these sites are about 60% and 40%, respectively.

Experimental Design

The study area was laid out according to a split-plot factorial (randomized block) design, similar to that described in Kirk (1982). Each of the 24 nursery treatment combinations was represented by two replicates per block per site. Each replicate was assigned at random to a row plot; each row contained about 25 seedlings. Seedling spacing was at 2 m within rows and 1 m between rows. One of the two replicates per block was assigned at random for destructive sampling while the other was retained as a permanent plot.

Data Collection

After shoot growth cessation in late September 1987, eight seedlings per row were sampled at random for study. A total of 1104 plants were examined; this was 48 less than planned because of seedling mortality.

Seedling shoot growth in the field in 1987 occurred through internodal elongation of stem units that originated from the overwintering bud, and from free and lammas growth. The stem units in the bud are predetermined as they were formed during nursery culture. Free growth occurred in the first season of field growth through production of new needle primordia followed by immediate internodal expansion. Lammas growth occurred through the premature flushing of the new bud that was formed in the same season. It was not possible to distinguish needles produced during free growth from those present in the overwintering bud. However, a good estimate could be made of these numbers because numbers of needle primordia in the overwintering bud were recorded at the end of the nursery experiment (O'Reilly et al. 1989b). The lammas portion of the shoot was easy to identify by the presence of bud scales on the new shoot in addition to those of the new overwintering bud. Also, some free growth commonly takes place as the lammas bud elongates; all growth distal to the lammas bud scales was considered as lammas growth despite this fact. The 1987 shoot was divided into two portions for the purpose of this study, the predetermined-free and the lammas growth sections.

The following data were recorded from the 1987 shoot of each seedling: (1) total shoot length; (2) length of lammas shoot; numbers of needles or stem units[5] (NSU) in the (3) predetermined-free (4) and lammas growth sections of shoot; and (5) numbers of bud scales at base of the lammas shoot. New variables calculated from these data included: (6) total NSU, i.e. (3) + (4) + (5); and (7) lammas NSU, i.e. (4) + (5). Stem unit length (SUL) was calculated for the (8) whole shoot and for the (9) predetermined-free and (10) lammas portions of the shoot by dividing shoot length by NSU for the appropriate portion.

Data Analysis

Data were analysed according to a modified version of the split-plot factorial (randomized block) design as outlined in Kirk (1982). The Spssx MANOVA procedure (Spssx Inc. 1986) using unique sums of squares was employed in all analyses. The error term for each factor (e.g. site) was the interaction of that factor by block within site (e.g. site x block within site). Each factor interaction(s) (e.g. day length x moisture) was similarly tested by the interaction of that factor interaction by block within site (e.g. day length x moisture x block within site) etc. In total, 16 error terms were created for each variable analysed.

RESULTS

Shoot length is determined by its components, NSU and SUL. Therefore, the effect of nursery pretreatment and site on these components are considered before addressing their combined effect on shoot length. Only mean pretreatment and site effects that are most representative of the data are presented in the figures.

Number of Stem Units and Lammas Growth

Planting site ($p<0.001$) and the nursery pretreatments - moisture ($p<0.01$), day length ($p<0.05$), cavity size ($p<0.05$), lift ($p<0.05$) - and the interactions of day length by lift ($p<0.01$) and site by day length by lift ($p<0.01$)

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[5] A stem unit is "an internode, together with the node and nodal appendages at its distal extremity" (Doak 1935). Needles and lammas bud scales are stem units of interest in this study; both types underwent internodal expansion.

significantly influenced final NSU. However, the results for all except site effects are confounded by differences among pretreatments in preformed NSU.

Differences among nursery pretreatments in NSU on the NW site within lift N seedlings (fig. 1A) closely paralleled final needle primordium numbers recorded in the nursery study (O'Reilly et al. 1989b). Seedlings pretreated to moisture stress and long days had the least number of needle primordia at planting, the effect of the former being greater than the latter. Seedlings from the SDW pretreatment had the greatest number of primordia at planting.

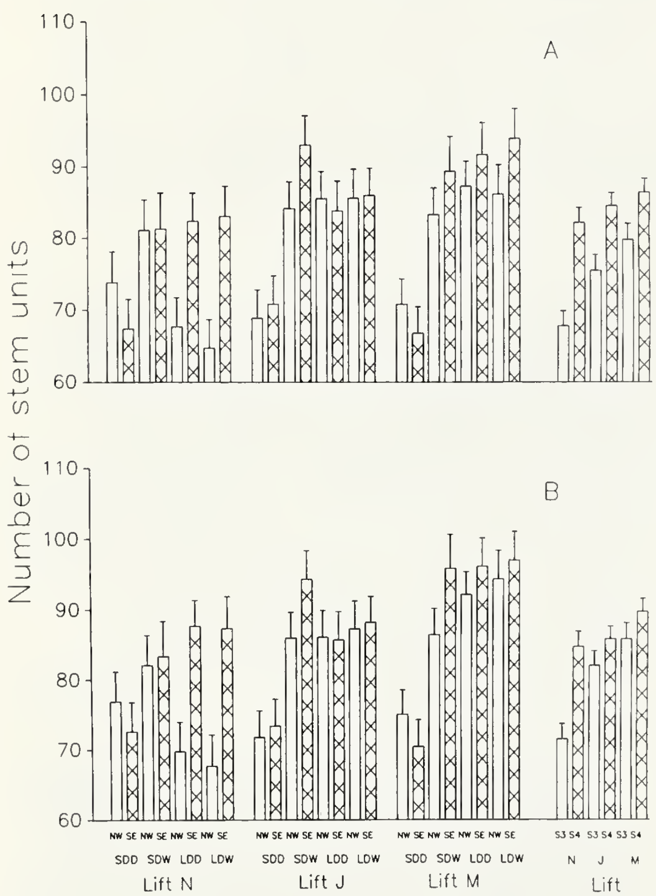

Figure 1.--Mean number of stem units before (A) and after (B) lammas growth has occurred during the first year of field establishment on two sites in seedlings of western hemlock that were subjected to different nursery pretreatment combinations. Means are taken across other pretreatments or sites not included in that hierarchy. N, J, and M indicate November, January and March lifts, respectively. SDD, SDW, LDD and LDW refer to short-day dry, short-day wet, long-day dry and long-day wet pretreatment combinations, respectively. NW and SE indicate north-west and south-east sites, respectively. S3 and S4 refer to small and large styroblock cavity sizes, respectively. Vertical lines indicate 1 SE.

Seedlings from the SE site usually produced the most NSU, but this varied with nursery preconditioning. Seedlings from SDD had no free growth or produced few new stem units during free growth across all lifts and on both sites. Few new stem units were produced during free growth in seedlings pretreated to SDW from any lift-storage precondition on the NW site, but those from lifts J and M produced some free growth stem units on the warmer SE site. Seedlings of both moisture levels pretreated to LD showed a similar pattern across all lifts and both sites. Within the November-lifted stock, seedlings pretreated to LD showed a much different pattern than those that received SD. Seedlings pretreated to LD within lift N produced many new stem units during free growth on the SE site, but few on the NW site. Seedlings from other lifts within this pretreatment produced many stem units during free growth.

Seedlings from S4 had greater NSU than those from S3, mainly due to differences in fixed NSU (O'Reilly et al. 1989). On average, seedlings from S4 had 10 needle primordia more at planting than those from S3. However, there were large differences in NSU between lifts for seedlings from S3 at the end of the field season, but small differences in those from S4 (fig. 1A). These differences occurred mainly due to the greater amounts of free growth stem units produced in S3 seedlings from lifts J and M and in those from S4 within lift N. Differences were relatively consistent across the pretreatments within each lift.

The frequency of lammas growth varied with site and nursery pretreatment (fig. 2). The highest frequency of lammas shoots was in seedlings from lifts N and M, especially in those from S3. Differences in lammas shoot frequencies combined with variation in lammas NSU are reflected in final NSU values (fig. 1B). Note the general increase in NSU in seedlings from lift M and in those from S3 within the J and M lifts. Seedlings from the smaller cavities produced the least NSU, especially those from lift N.

Stem Unit Length

Stem unit length varied significantly due to nursery pretreatments - lift ($p<0.001$), day length ($p<0.05$) and day length by moisture stress ($p<0.05$). Lifting date had a large and consistent effect on mean SUL, but the influence of dormancy induction pretreatment was variable (fig. 3). Plants from lift N had the shortest SUL. Seedlings pretreated to LD had larger mean SUL than those from SD. Plants of both moisture levels in the nursery within LD had similar SUL but those stressed within SD had very short SUL. Planting site by day length effects appear

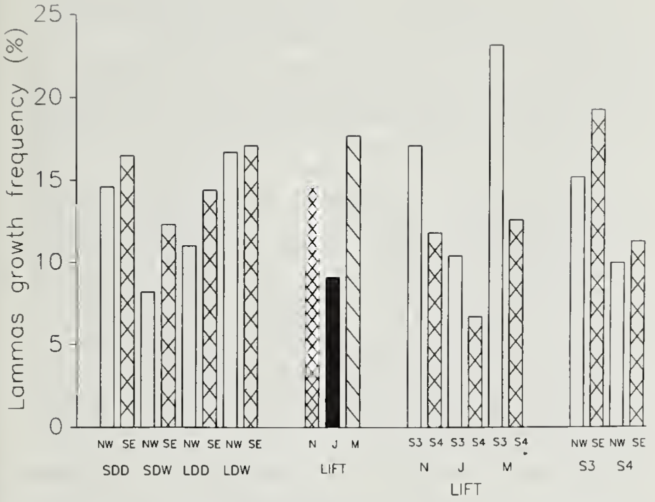

Figure 2.--Lammas growth frequencies (%) during the first year of field establishment on two sites in seedlings of western hemlock that were subjected to different nursery pretreatment combinations. Means are taken across other pretreatments or sites not included in that hierarchy. N, J, and M indicate November, January and March lifts, respectively. SDD, SDW, LDD and LDW refer to short-day dry, short-day wet, long-day dry and long-day wet pretreatment combinations, respectively. NW and SE indicate north-west and south-east sites, respectively. S3 and S4 refer to small and large styroblock cavity sizes, respectively.

substantial, although these were not significant ($p<0.09$). Site means are presented because they had an important effect on final shoot length when combined with the influence of NSU. Plants from the SE site had larger SUL when pretreated to LD and SDD, while those pretreated to SDW showed the reverse pattern. There were no significant differences in SUL between the lammas and fixed-free portions of the shoot.

Shoot Length

Field height growth was significantly affected by the nursery pretreatments - lifting date ($p<0.001$), day length ($p<0.01$), moisture ($p<0.05$), cavity size ($p<0.05$) and day length by site ($p<0.01$), moisture by day length ($p<0.05$).

Seedlings from SDD conditions in the nursery had the shortest shoots due to the short SUL and low NSU (fig. 4A). Shoot length in those pretreated to SDW were much greater than those pretreated to SDD because they had more stem units in their overwintering buds (O'Reilly et al. 1989b) and had greater SUL. Number of free growth stem units was not a major factor for seedlings pretreated to SD. Shoot length in SDW seedlings was similar on both sites, but this was achieved

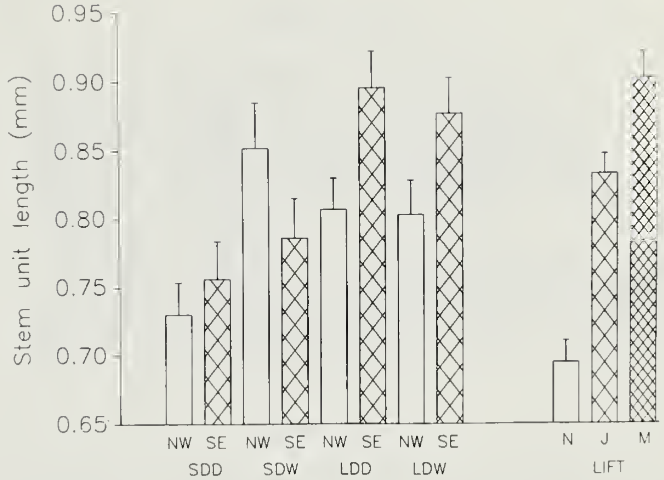

Figure 3.--Stem unit length at the end of shoot growth during the first year of field establishment on two sites in seedlings of western hemlock that were subjected to different nursery pretreatment combinations. Means are taken across other pretreatments or sites not included in that hierarchy. N, J, and M indicate November, January and March lifts, respectively. SDD, SDW, LDD and LDW refer to short-day dry, short-day wet, long-day dry and long-day wet pretreatment combinations, respectively. NW and SE indicate north-west and south-east sites, respectively. Vertical lines indicate 1 SE.

in different ways. Seedlings on the NW site had greater SUL but had fewer stem units than those on the SE site. Seedlings from both moisture levels of the LD pretreatments had similar final shoot length. Shoot length of plants from the NW site of this pretreatment was similar to those from SDW. The greater growth achieved in the LD pretreated plants on the SE site was mainly due to the greater SUL, although NSU produced during free and lammas growth also contributed.

Differences in shoot length due to cavity size resulted from differences in NSU only. Seedlings from the larger cavities had greater preformed NSU (O'Reilly et al. 1989b). However, seedlings from S3 produced more free growth and lammas growth than those from S4 (fig. 4B).

Lammas growth had the largest effect on seedlings from S3, especially in those pretreated to LD. This effect of LD was not apparent in the NSU (fig. 1) and lammas frequency data (fig. 2); the much greater SUL combined with greater NSU resulted in substantial shoot length differences in these seedlings. Changes in final shoot length due to lammas growth were generally greatest in seedlings from lifts N and M and on the SE site, especially in those from SDD on that site.

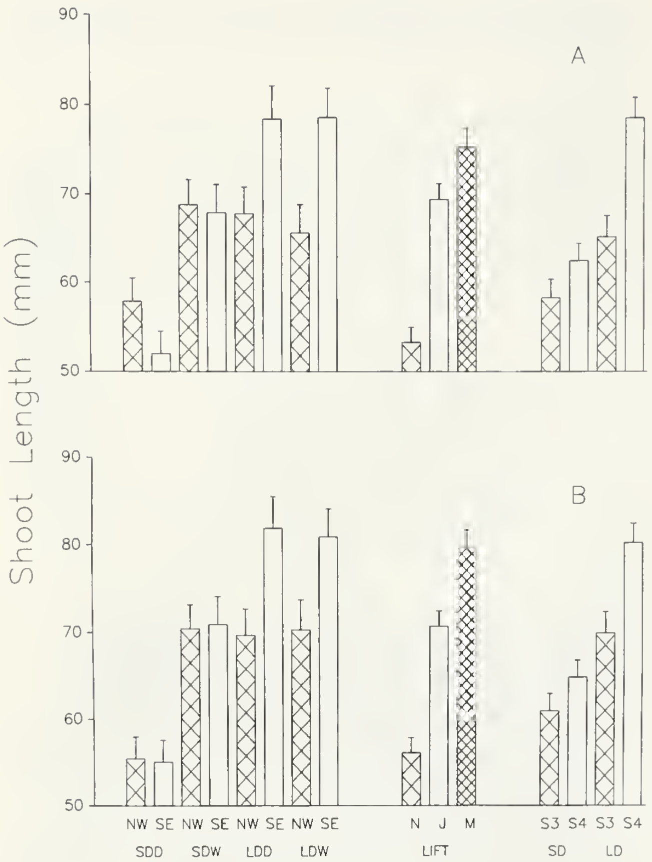

Figure 4.--Shoot length before (A) and after (B) lammas growth has occurred during the first year of field establishment on two sites in seedlings of western hemlock that were subjected to different nursery pretreatment combinations. Means are taken across other pretreatments or sites not included in that hierarchy. N, J, and M indicate November, January and March lifts, respectively. SDD, SDW, LDD and LDW refer to short-day dry, short-day wet, long-day dry and long-day wet pretreatment combinations, respectively. SD and LD refer to short- and long-day pretreatments, respectively. NW and SE indicate north-west and south-east sites, respectively. S3 and S4 refer to small and large styroblock cavity sizes, respectively. Vertical lines indicate 1 SE.

DISCUSSION

Shoot length is determined by the number of stem units and stem unit length; the former is considered far more important than the latter in this regard (Cannell et al. 1976). These components of shoot length are thought to vary independently (Cannell 1979), although this may not always be the case (Kremer and Larson 1983; Bongarten 1986; Hallgren and Helms 1988). Most NSU in seedlings of western hemlock were preformed, i.e. they were initiated by activity of the apical meristem during nursery growth (O'Reilly et al. 1989b). In contrast, SUL is determined by activity of the intercalary meristems located between the needle primordia and subsequent cell elongation. Therefore, final SUL is determined by processes that become activated mostly during field growth.

Variation in NSU due to nursery pretreatment in the portion of the shoot that elongated before lammas growth took place (fig. 1A) largely agreed with that measured in the nursery study (O'Reilly et al. 1989b). The influence of lifting date mostly reflected differences in NSU produced during free growth because date of lifting had little effect on final primordium numbers in the nursery study (O'Reilly et al. 1989b). In addition, planting site had a significant influence on NSU across all lifts, site effects being largest within the LD November-lifted stock.

Seedlings from the short days and moisture stress pretreatment had short SUL, with little difference due to planting site. These seedlings produced few additional stem units during free growth, and combined with their very short SUL, produced very short shoots. Seedlings with a large number of needles are most susceptible to moisture stress during elongation (Hallgren and Helms 1988), perhaps accounting for the shorter SUL in seedlings from SDW growing on the warmer SE site (fig. 3). Furthermore, seedlings from the SD pretreatment, especially those from SDW of lift M, flushed their buds more rapidly than other seedlings (O'Reilly et al, unpubl.). Flushing rates were most rapid on the SE site, perhaps making them susceptible to moisture stress during early shoot elongation. The 1987 growing season was warm and dry at the study sites[6]. Also, competition for metabolites among elongating stem units may have resulted in the shorter SUL on the SE site where some free growth took place, a hypothesis first proposed by Kremer and Larson (1983) to explain the negative correlation found between NSU and SUL in seedlings of *Pinus banksiana* Lamb. The large number of preformed needles in seedlings from SDW (O'Reilly et al. 1989) combined with adequate SUL allowed good shoot growth in the field. Seedlings pretreated to LD in this study were of higher physiological quality (Arnott et al. 1989), thus explaining their superior shoot growth achieved through increased SUL as well as through the production of additional NSU during free and lammas growth, especially on the SE site.

Differences in final shoot length due to cavity size were attributable to differences in NSU only. The larger NSU that were predetermined in seedlings from S4 than in those from S3 (O'Reilly et al. 1989b) explained most of these differences. Similarly, plant spacing in the

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[6]Data on file, Canadian Forestry Service, Victoria, B.C.

nursery had a large effect on height growth up to 3 years after field planting in seedlings of Douglas fir (van den Driessche 1984).

Interestingly, lammas growth was most frequent in seedlings from S3 and in those from lifts N and M. Because of the superior physiological quality and greater vigour of lift M stock (Arnott et al. 1989), it is not surprising that they had a high frequency of lammas shoots. The relatively high frequency of lammas growth in the November-lifted stock probably was related to the physiological and developmental characteristics of these seedlings. Seedlings from this lift flushed much later in the field than those from other lifts (O'Reilly et al, unpubl.), probably because its dormancy intensity was very high at time of planting (Arnott et al. 1989). In addition, these plants began bud development at an earlier date than those from other lifts, and they often resumed growth after producing a few bud scales only (O'Reilly et al., unpubl.). The late release from dormancy combined with earlier date of bud formation perhaps made these plants prone to lammas growth. Lammas shoot length was very short in these seedlings because they produced few lammas stem units and had short SUL. The high frequency of lammas growth on seedlings from S3 is more difficult to explain. Seedlings from S3 were smaller but had greater apical dominance than those from S4 (O'Reilly et al. 1989a); such plants may have been more responsive to environmental changes that induce lammas growth.

The confounding effect of seedling size at planting on shoot growth except for that of cavity size has not been addressed in this paper. Seedlings treated to LD were about 25% taller and were much more heavily branched (O'Reilly et al. 1989a). Moisture stress had a smaller effect on seedling size while lifting date had a negligible effect on these characteristics. Seedlings treated to SDW grew adequately in the field relative to planting height, but these plants had the advantage of having many preformed stem units. Seedling size at planting was not considered because it would complicate data analysis and interpretation further.

CONCLUSIONS

Spring lifting followed by immediate field planting provide the best shoot growth during the first year of field establishment in western hemlock seedlings. Seedlings subjected to long days during dormancy induction in the nursery achieved better shoot growth after outplanting than those treated to short days. Moisture stress in the nursery had little effect on shoot growth in the field of seedlings from the LD pretreatment but greatly reduced shoot growth of those from the SD pretreatment. Because most stem units were preformed during bud development in the nursery, differences in SUL had a larger impact on shoot length than differences in NSU. Lammas growth was most frequent in seedlings from the smaller cavities and in those from the November and March lifts.

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245 Field Performance of Five Interior Spruce Stock Types with and without Fertilization at Time of Planting[1]

Craig Sutherland[2] and Teresa Newsome[3]

Abstract.--The purpose of this experiment was to compare the initial field performance of interior spruce seedlings by container size, root pruning, and fertilization at time of planting. Increasing the container size significantly improved seedling performance after five growing seasons. Mechanical or chemical root pruning and fertilization at time of planting made no significant improvements to seedling performance.

INTRODUCTION

Field performance of spruce seedlings is a concern to both nurserymen and foresters because of the inherent slow initial growth of spruce and the fact that most spruce sites are prone to invasion of non-crop vegetation. The Cariboo Forest Region is no exception. A study concerning plantation performance in the Cariboo found that both bareroot and small container (PSB 211) spruce obtained an average height of only 50 cm after five growing seasons (Vyse, 1981). Many spruce plantations quickly get chocked out by such species as fireweed (Epilobium angustifolium) which restrict light availability, nutrient and water uptake and cause mechanical damage to seedlings through vegetation press. If spruce could compete more effectively with non-crop vegetation by initially being larger in height and caliper and by exhibiting faster growth responses one would expect the seedlings would be at a competitive advantage to the brush.

[1]Paper presented at the 1988 Conference of the Western Forest Nursery Council and Forest Nursery Association of British Columbia, Vernon, British Columbia, August 8-11, 1988.
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The objectives of this experiment were to 1) compare the early field performance of five experimentally produced containerized stock types; 2) assess the effects of root pruning; and 3) assess the effects of slow-release fertilizer applied at the time of planting.

This trial was established in four Forest Regions of British Columbia. The results presented in this paper are from the trial estabished in the Cariboo Forest Region.

METHODS

The trial was established on a recently burned clear cut in the Cariboo Forest Region, situated in the interior of British Columbia. The site was classified according to the Biogeoclimatic Classification System (Coupe' and Yee, 1982) as the Interior Cedar Hemlock (h) Subzone with an elevation of approximately 950 m.

The trial was established as a split-plot design with fertilizer as the main plot factor and stock type as the split-plot factor. Four blocks were established on the site.

Five different stock types of British Columbia interior spruce (Picea glauca x engelmannii) were grown at the Ministry of Forests' North road Lab in 1980, in Victoria, B.C. by A.N. Burdett in 1980 (table 1).

Table 1.--Five stock types of British Columbia interior spruce

Stock Type	Root Pruning
CBR 1010 1+0 [1]	Boxed (Mechanical)
PSB 615 1+0 [2]	None
PSB 415 1+0	Copper (chemical)
PSB 415 1+0	None
PSB 313 1+0	None

1 Container grown bareroot from a (10 x 10 x 10 cm boxed container)

2 Plug Stryro Block container

Forty grams of Osmocote fertilizer (18-6-12) was placed in a 15 cm radius around the base of each seedling at the time of planting. One half of each stock type was fertilized and the other half left as a control.

All seedlings in the five stock types by two fertilization treatments were monitored at the end of each growing season for seedling survival, total height (cm), leader growth (cm), stem diameter (mm), condition and for vegetation cover. An ANOVA was used to analyse the data.

RESULTS AND DISCUSSION

Stock Type

Seedling Survival

Seedling survival was excellent across all treatments after five growing seasons. There were no significant differences between average treatment survivals which ranged from 94 to 96%.

Seedling Height Growth

The PSB 615 and CBR 1010 stock types were significantly taller than the other stock types when planted and they have been able to maintain this height superiority for five growing seasons (fig. 1). The total heights of the PSB 615 and CBR 1010 container seedlings after five years were close to one meter in height which was higher than the competing non-crop vegetation. These averages are significantly taller than the 70 to 80 cm heights obtained by the other three stock types which were still competing strongly for light with the non-crop vegetation.

This height superiority can be further illustrated by looking at relative growth rates (fig. 2). Relative growth rate (R.G.R.) is a comparison of a stock types total seedling height and its previous year's height. Relative growth rate is expressed by the slope of each line. Since each stock types R.G.R.'s have parallel slopes, this would indicate that the larger stock types (PSB 615, CBR 1010) are maintaining height superiority. The taller stock types are producing taller terminal leaders and are reaching a free growing state sooner than the shorter stock types.

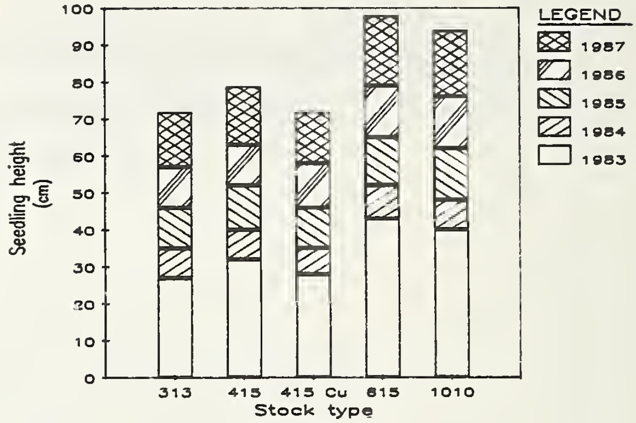

Figure 1.--Total seedling height of five interior spruce stock types by growing season.

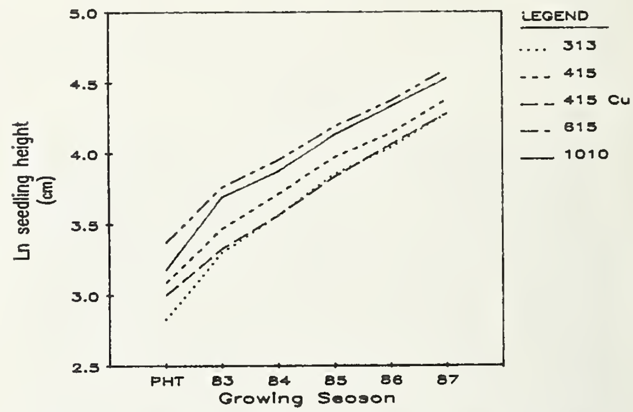

Figure 2.--Relative height growth rate of five interior spruce stock types.

Seedling Diameter Growth

The PSB 615 and CBR 1010 stock types were significantly larger in diameter than the other stock types when planted and they have also been able to maintain a diameter superiority for five growing seasons (fig. 3). The total diameters of the PSB 615 (28 mm) and CBR 1010 (25 mm) seedlings are significantly larger than the 19 to 22 mm diameters produced by the other three stock types. The taller stock types are now receiving increasing amounts of light and so are able to allocate more carbohydrates to the root systems which directly increases diameter growth.

Again this diameter superiority can be further illustrated by looking at relative growth rates (fig. 4). Since the slopes of the lines are parallel the R.G.R.'s are comparable. The larger stock types which have larger root collar diameters are becoming more resistant to vegetation press than the smaller stock types.

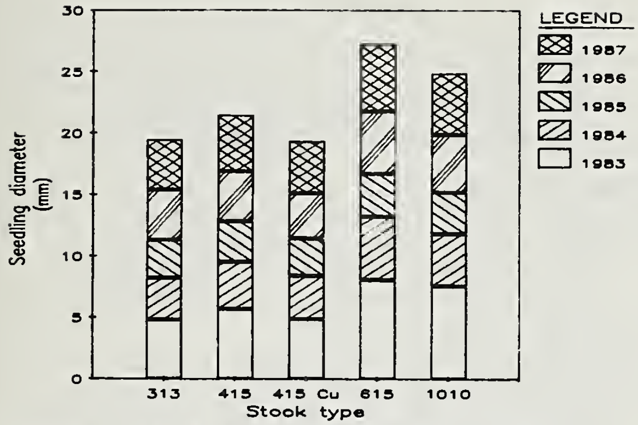

Figure 3.--Total seedling diameter of five interior spruce stock types by growing season.

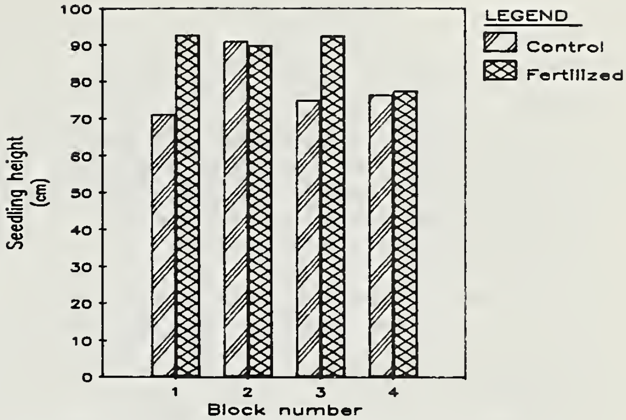

Figure 5.--Total seedling height of the fertilized and control treatments for all stock types within each block.

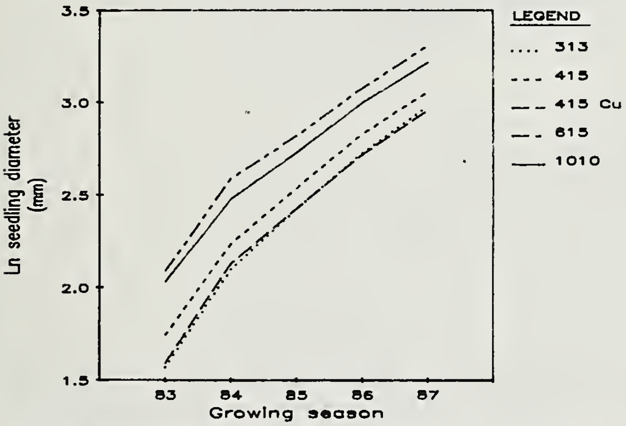

Figure 4.--Relative diameter growth rate of five interior spruce stock types.

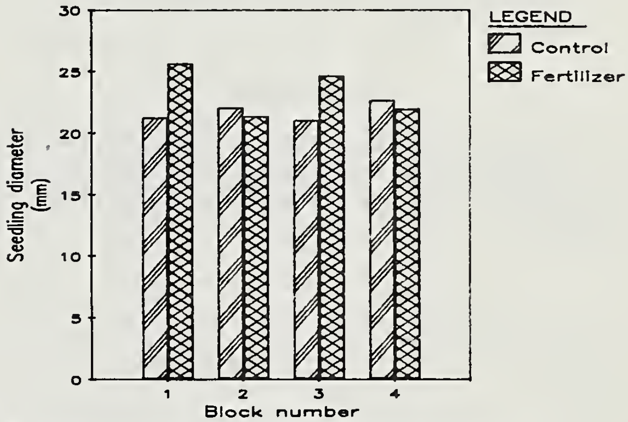

Figure 6.--Total seedling diameter of the fertilized and control treatments for all stock types within each block.

Fertilization

Osmocate fertilization produced an irregular response but overall it did not significantly improve seedling height or diameter growth. Brockely (1988) stated that response to fertilization has not been consistent in the past. This study confirms his statement by identifying treatment response irregularities between the four blocks (fig. 5 and 6). Although this study was not designed to test site differences, the data suggests that the better growth responses to the fertilizer treatment (Block 1 & 3) occurred on mesic sites and the poor growth responses (Block 2 & 4) occurred on submesic and subhygric sites respectively.

Root Pruning

The purpose of mechanical or chemical root pruning was to stimulate lateral root development in container plugs. The height and more importantly diameter growth responses indicate that the mechanical root pruning of the CBR 1010 stock and the chemical root pruning of the PSB 415 copper treated stock had little or no effect on seedling growth.

Insect Damage

Pissodes strobi (terminal spruce weevil) attacked approximately 10 percent of the PSB 415 and 615 and CBR 1010 seedlings and 5 percent of the PSB 313 and 415 CU seedlings. The attack has concentrated on the taller stock types and where the frequency of tall seedlings was high. This insect attack once again points out that seedlings reaching a height defined, free growing state may not necessarily be free to grow.

CONCLUSIONS

1. Seedling survival ranged from 94 to 96 percent across all treatments after five growing seasons.

2. The PSB 615 and CBR 1010 stock treatments produced significantly larger height and diameter growth responses than the PSB 415, 415 CU and 313 stock treatments.

3. Fertilization produced irregular results but generally did not improve growth response.

4. Mechanical or chemical root pruning had little or no effect on seedling growth response.

5. *Pissodes strobi* are attacking young seedlings and protection measures must be taken once seedlings have reached a free growing status.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. A.N. Burdett for initiating and coordinating the trial and Mr. A. Vyse for establishing the trial in the Cariboo.

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Impact of Lift Date and Storage on Field Performance for Douglas-fir and Western Hemlock[1]

B.G. Dunsworth[2]

Abstract.--This study was established to assess the impact of changes in seedling morphology and physiology on outplant performance of western hemlock and Douglas-fir.

The six lift/store regimes in this experiment led to greater changes in seedling physiology than seedling morphology. The regimes created a wide range of dormancy intensities and frost hardiness for both species. Frost hardiness, as assessed by electrolyte leakage, was more closely related to dormancy intensity than was foliage browning. Storage regimes reduced the rate of dormancy release and maintained frost hardiness relative to no storage.

Field performance results from unwatered, raised beds indicate that early planting dates (Jan. 15) had the best relative volume growth. Storage maximized relative volume growth for both species for the March 15 and May 15 planting dates. Electrolyte leakage and dormancy intensity were the best predictors of volume growth.

ACKNOWLEDGEMENT

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INTRODUCTION

For a number of years there has been a contentious debate among coastal nursery growers and field users about the appropriateness of winter lifting and storage of planting stock (Stone and Schubert 1959a, Hermann et al. 1972, Jenkinson and Nelson 1978, Krueger 1966, Nelson and Lavender 1979). Today, many foresters feel that cold storage is detrimental. They subsequently demand hot planting stock when they can, particularily for late spring planting.

This sentiment has been reinforced by erratic survival and poor growth in Douglas-fir, western red cedar, and ponderosa pine bareroot stock cold-stored for several months prior to planting (Stone and Schubert 1959b, Stone et al. 1961, Hocking and Nyland 1971, Curran and Dunsworth 1987, Van Den Driessche 1977).

Cold storage has been associated with the following problems:

- molds,
- loss of carbohydrate reserves,
- reduction in root growth capacity,
- loss of dormancy intensity, and
- reduced frost hardiness and stress resistance.

Although the potential for physiological deterioration exists, the literature indicates that the rate of deterioration is accelerated without cold storage (Ritchie and Dunlap 1980, Burdett and Simpson 1984, Garber and Mexal 1980, MacDonald et al. 1983).

However, cold storage may create an acclimation problem, particularily with late spring planting. Investigations with boreal species in eastern Canada suggest that the stresses of acclimation may be greatest for cold-stored stock (Grossnickle and Blake 1987). Whether this is true in coastal species and whether the maintenance of a higher level of stress resistance is a compensating factor has yet to be determined.

Eliminating cold storage reduces nursery operating costs but creates a logistical problem. Persistent delays in handling the last season's crop leads to delays in starting the next season's crop. Coastal, container nursery growers need to determine if there is good biological foundation to the belief that cold storage is a detrimental practice. They also

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1 Paper presented at the 1988 Western Forest Nursery Association Meeting, August 8-11 (Vernon, B.C., Canada)

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need to know if there is sufficient variation among seedlots to justify a range of winter lift regimes.

Our initial look at the problem focused on:

1. The predictive relationships among morphological and physiological characterizations at lift with subsequent field performance.
2. The progression and interrelationships among physiological characterizations from January to May under stored and non-stored conditions.
3. Potential optimum lift/store regimes.

METHODOLOGY

This experiment consists of two parts:

1. Seedling characterization.
2. Seedling performance.

The experimental approach is to create as wide a range of morphological and physiological kinds of seedlings using species, cavity size and lift/store regime as is practicable. These are then exposed to a simulated outplanting, under conditions where soil moisture and temperature can be measured and controlled. Seedlings able to maximize survival and growth under these conditions can then be associated with a specific cultural regime.

Seed Source and Lift/Store Treatments

The following species and stocktypes were grown at the Angus P. MacBean Nursery during 1985:

Table 1.--Seedlots and stocktypes used for Douglas-fir and western hemlock.

Douglas Fir Seedlot/Elevation	Stock Type PSB 313	PSB 415	Western Hemlock Seedlot/Elevation	Stock Type PSB 313
4504/579	X		7311/150	X
7320/915	X		18752/416	X
4505/610	X	X		

The lift/store regimes shown in Table 2 were applied to each of the species and stocktypes shown in Table 1.

Seedling Characterization

Seedlings were characterized for morphology and physiology at lift and at the end of storage.

Morphology

Twenty-five trees per treatment (five trees for five replicates) were assessed for height, caliper, shoot and root dry weight.

Physiology

Seedlings from each treatment were assessed for Root Growth Capacity (in two environments),

Table 2.--Lift dates and storage duration treatments for Douglas-fir and western hemlock.

Lift Date	Storage Duration (months) at +2 C. 0	2	4
01/15/86	T1	T2	T3
03/15/86	T4	T5	
05/15/86	T6		

Dormancy Release Intensity, and Frost Hardiness (foliage browning and electrolyte leakage).

Root Growth Capacity.--Twenty-five seedlings (five trees from five replicates) per treatment were grown for one week in a peat/vermiculite/sand medium (2:1:1) in each of two environments (75% RH, 16 hr photoperiod, and 400 μmol/s/m^2 common to both):

1. 22 C/18 C (day/night) (D/N)
2. 30 C/25 C (D/N)

Seedlings were kept at field capacity for one week and assessed for root elongation using the index of root growth (IRG) (Burdett 1979).

Dormancy Release Index.--Twenty-five trees (five trees from five replicates) per treatment were assessed for number of days to budburst. The test environment was a 20 C D/N greenhouse with 16 hour photoperiod. Seedlings were kept at field capacity for the duration of the test. The index was calculated as:

DRI= 10/# days to budburst (Ritchie 1984)

Frost Hardiness.--The risk of frost damage was assessed using foliage tissue in two ways:

1. Foliage Browning--qualitative (visual) assessment of the percent of foliage browned after exposure (-18 C) and one week of growth at room temperature and field capacity.
2. Electrolyte Leakage--quantitative assessment of cell membrane leakage of electrolytes due to stress or damage by frost (-18 C). Assessment consists of a comparison of conductivity measures for diffusate from frost damaged, undamaged, and heat killed foliage (Colombo and Cameron 1986).

Seedling Performance Study

The field study was designed as a completely randomized experiment consisting of six lift and store regimes and six species/stocktype treatments each replicated three times. Replicate plots consisted of twenty tree-row plots at 15 x 15 cm spacing. This test was planted into a 4 m x 8 m x 70 cm wooden soil box consisting of an alluvial,

silty sand soil. The box was covered with a 6 mm, polyethylene sheet roof. This allowed rain to be excluded and still achieve approximately 75% full sunlight.

All seedlings were grown in the raised beds for one growing season. In December, all surviving seedlings were measured for height and caliper and carefully excavated. Shoot and root dry weights were determined for treatments; replicates were pooled.

The field performance results described here pertain to the dry moisture regime. This regime received no watering during the growing season. Soil tension at 20 cm exceeded -5 bars for greater than 100 days; soil temperature at 10 and 20 cm exceeded 20 C for up to 60 days.

RESULTS AND DISCUSSION

Seedling Characterization

Morphology At Lift

Height over all lift dates ranged from 16 to 23 cm. Western hemlock seedlings tended to be taller than Douglas-fir. Caliper ranged from 2.2 to 3.7 mm, with the latest lift having the largest calipers for all seedlots.

Shoot dry weight extended from 0.8 to 3.0 g, with a consistent trend of increasing weight from later lift dates. Western hemlock had consistently higher shoot weight than Douglas-fir for all lifts. Root dry weight varied from 0.6 to 1.6 g and exhibited a consistent increase with later lifts. This was less dramatic than increases in shoot dry weight.

Shoot to root ratios tended to increase with later lift dates. Western hemlock had larger ratios than Douglas-fir for the first two lifts, but by May 15 both species were comparable (Figure 1).

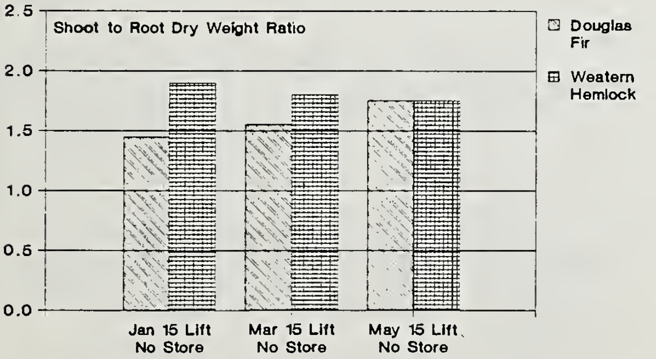

Figure 1.--Shoot to root ratio for three lift dates averaged by species.

The other measures of seedling balance (height:caliper and caliper:mass) tended to decrease with later lifts (Figure 2).

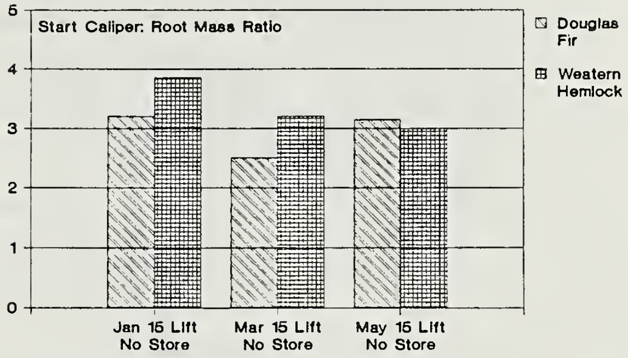

Figure 2.--Caliper to root mass ratios for three lift dates averaged by species.

Species differences in morphology were most pronounced for the earliest lift. Western hemlock was taller, thinner, and less balanced than Douglas-fir. These differences were negligible by the last lift.

Physiology At Lift and During Storage

Root growth capacity (index of root growth) was high for both hot (30/25 C, D/N) and cool (22/18 C, D/N) tests over all species and lift/store regimes. The cool test tended to have higher values and a slightly narrower range than the hot test (Figure 3). In both tests, western hemlock had higher RGCs than Douglas-fir for most lift/store regimes.

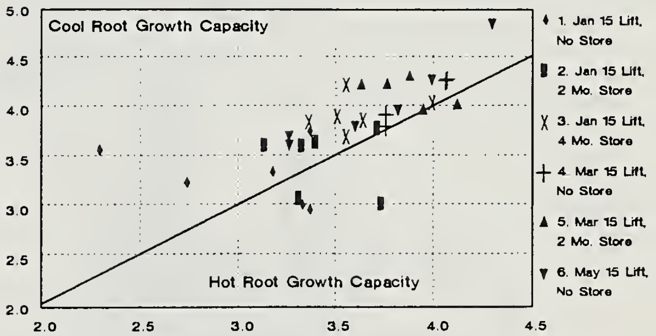

Figure 3.--Comparison of hot and cool root growth capacity test results (points are species/stocktype averages).

In assessing the progression of RGC over lift dates, Douglas-fir tended to increase RGC to March 15 and then decrease slightly to May 15. This was most pronounced in the hot test. Western hemlock, on the other hand, increased RGC consistently with later lift dates. Storage duration did not have a

significant negative effect on RGC in either species.

Dormancy intensity consistently weakened (index values increased) with increasing lift date (Figure 4). The impact of storage at both January 15 and March 15 was to reduce the rate of dormancy release relative to unstored stock for the same planting date. Douglas-fir had slightly more rapid dormancy release than western hemlock for both stored and unstored comparisons.

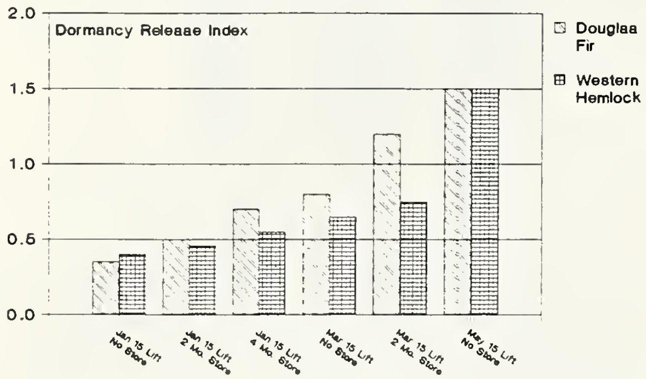

Figure 4.--Dormancy intensity averages for Douglas-fir and western hemlock over the six lift/store treatments.

Frost hardiness (-18 C) weakened with later lifts. The largest difference occurred between January 15 and March 15 lifts (Figure 5). Differences between species were not pronounced or consistent. Cold storage sustained good frost hardiness. In several seedlots, the stored versus non-stored differences in foliage browning were as high as 70 to 80 percent.

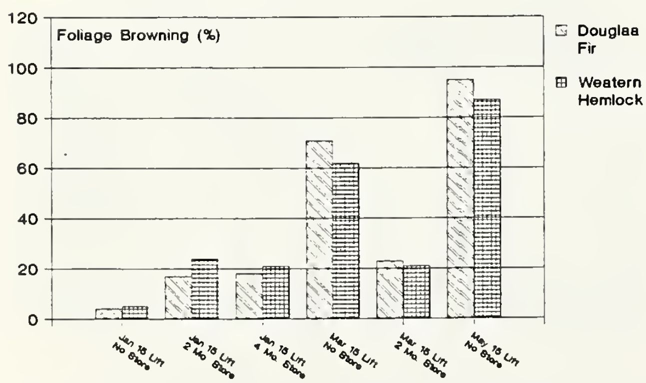

Figure 5.--Frost hardiness (foliage browning at -18 C) averages for Douglas-fir and western hemlock over the six lift/store treatments.

The conductivity test showed a more continuous pattern of change over the lift/store treatments and more consistent trends between species (Figure 6). Western hemlock was more frost tolerant than Douglas-fir with the odd exception of the last lift. From the March 15 lift to the May 15 lift, Douglas-fir showed a marked reduction and western hemlock an increase in index of injury.

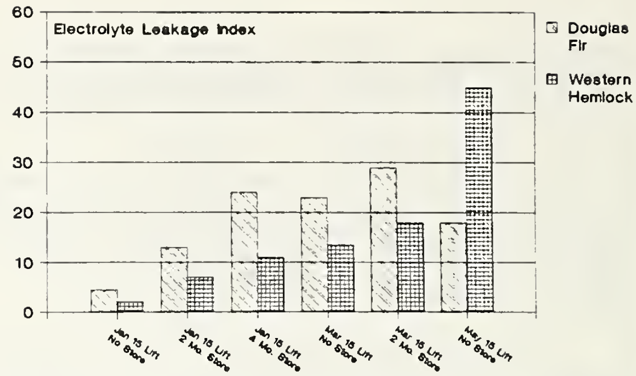

Figure 6.--Electrolyte leakage (Index of Injury) averages for Douglas-fir and western hemlock over the six lift/store treatments.

Comparisons Among Physiological Tests

The physiological tests in this study each provide slightly different information about seedling function. RGC indicates the ability to initiate and elongate roots. Electrolyte leakage indicates the degree to which the foliage has been stressed or damaged from frost exposure. The foliage browning test is a qualitative measure of cellular damage resulting from exposure to frost.

The comparison of "hot" versus "cool" RGC test environments has been discussed previously. In general, the cool test raised the RGC relative to the hot test (Figure 3) suggesting that the hot environment is beyond the photosynthetic optimum (W. Binder, pers. comm.). Also, rankings changed within and among lift/store treatments, with the most pronounced changes within treatments. For the remaining discussion, the comparisons to RGC will refer to the cool test which is now the B.C. Ministry of Forests' standard.

RGC and electrolyte leakage (index of injury) exhibited a positive linear relationship with dormancy intensity (dormancy release index) over all treatments. This appears to be at odds with the hypothesis put forward by Ritchie (1985) which suggested a strong, alternate cyclic pattern in RGC and frost hardiness as dormancy intensity weakens.

In the foliage browning frost hardiness test, the relationship with dormancy intensity partitions into two distinct groups: cold-stored and non-stored (Figure 7). The cold-stored stock from either the January 15 lift or the March 15 lift all had less than 40 percent frost damage. The non-stored stock ranged up to 95 percent damage by May 15. As Ritchie (1984, 1985) has shown for bareroot Douglas-fir, the effect of cold storage in this study was to reduce the rate of dormancy release and markedly reduce the rate of loss of cold hardiness.

Electrolyte leakage does not exhibit the same tight, treatment clusters as foliage browning (Figure 8). This may be because the test integrates stress and damage as they effect cell membrane permeability and function. Subsequently, for

the same level of foliage damage, we can have very different levels of electrolyte leakage within a given lift/store treatment.

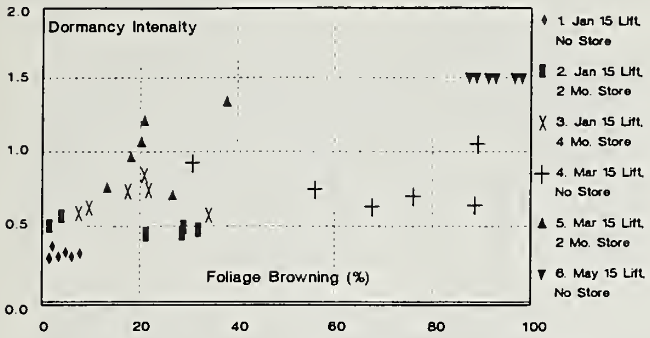

Figure 7.--Comparison of dormancy intensity and frost hardiness (foliage browning at 18 C) for Douglas-fir and western hemlock over the six lift/store treatments.

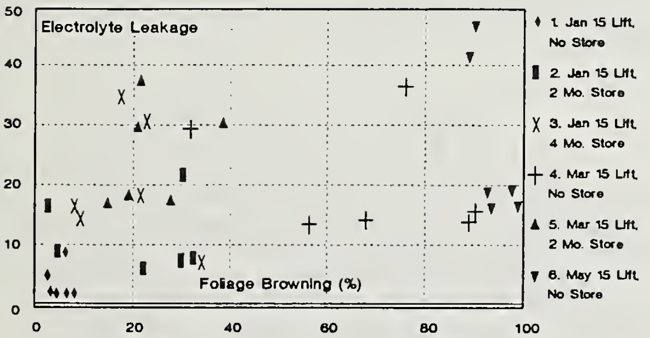

Figure 8.--Comparison of frost hardiness (foliage browning at -18 C) and electrolyte leakage (Index of Injury for Douglas-fir and western hemlock over the six lift/store treatments.

Field Performance

Survival

Survival ranged from 88 to 100 percent, indicating that all lift/store regimes resulted in stock with sufficient stress resistance to survive high seasonal root zone temperatures and persistent drought.

Growth

It should be realized that the nature of the lift/store and plant regimes is such that growing seasons may differ by as much as 120 days.

Height growth.--Relative height growth (growth/initial height) ranged from 0.35 to 0.80 (Figure 9). The trend was for later lifts to have greater height growth. Douglas-fir tended to have a narrower range than western hemlock and a much weaker tendency for later lifts to exhibit more growth. Storage appeared to have an indeterminate effect on Douglas-fir, but a marked negative effect on western hemlock.

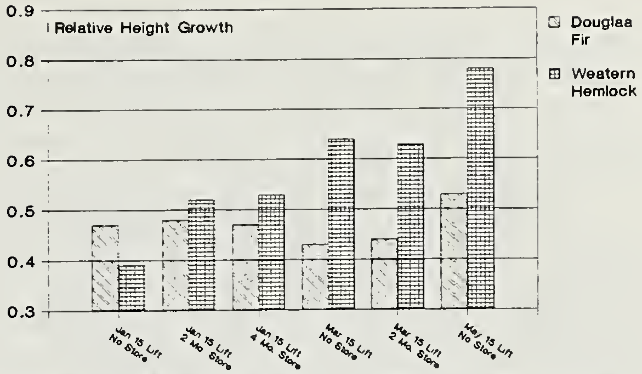

Figure 9.--Relative height growth (growth/initial height) averages for Douglas-fir and western hemlock over the six lift/store treatments.

Caliper growth--Caliper growth tended to show the reverse relationship to lift/store regimes that was evident with height growth. Early lifts had the best relative caliper growth. Stored stock had comparable or better caliper growth for March 15 or May 15 planting dates. The pattern of caliper growth over lift/store regimes tended to be more consistent between species than with height growth.

Volume growth--Relative volume growth (volume growth/initial volume) integrates height and caliper growth but with more emphasis on caliper than height. Subsequently, the pattern of volume growth over lift/store regimes mimics that of caliper growth.

Early lifts have the highest relative volume growth (Figure 10). Western hemlock and Douglas-fir tended to respond similarly to storage. Stored stock had comparable or better volume growth than non-stored stock for the same planting date. This was particularly evident for the May 15 planting date for both species where the January 15 lift with four months storage had 20 to 25 percent better relative volume growth than the March 15 lift with two months storage, and 50 to 75 percent better relative volume growth than non-stored stock.

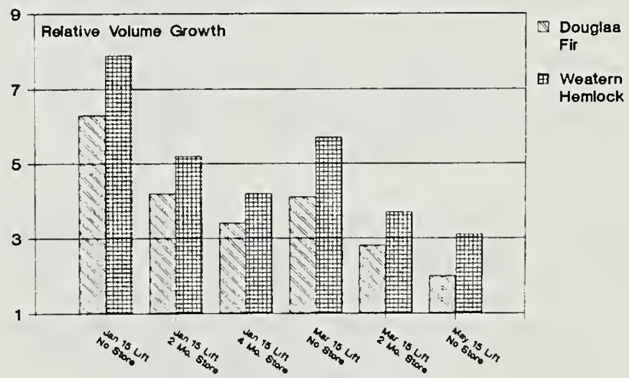

Figure 10.--Relative volume growth (growth/initial volume) averages for Douglas-fir and western hemlock over the six lift/store treatments.

These differences in height, caliper and volume growth are a function of length of growing season and of differing physiological responses to the outplanting environment. They result from changes in water relations and gas exchange which ulti-

mately impact on photosynthesis, total biomass production, and the partitioning of biomass above and below ground.

Biomass Production and Partitioning

Total biomass growth for both species ranged from 3.5 to 5.5 g dry weight. Western hemlock tended to produce more biomass than Douglas-fir for any given lift/store combination. Storage resulted in comparable or greater biomass production for both species for either the March 15 or May 15 planting dates. Storage differences were more pronounced for Douglas-fir.

The more marked difference in biomass production came from the way in which seedlots and species partitioned their seasonal biomass above and below ground (Figure 11). The general tendency over all lift/store regimes was for biomass to be allocated more below ground with later lifts.

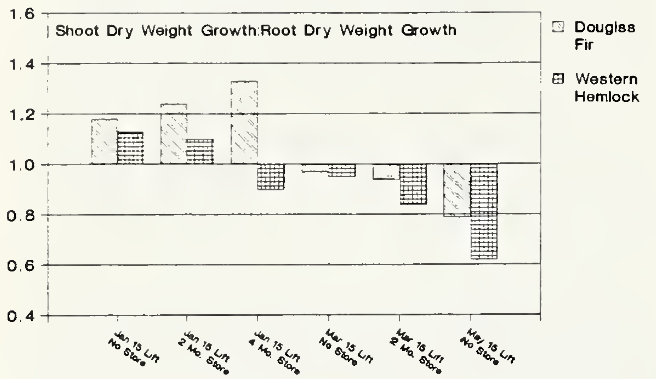

Figure 11.--Above and below ground biomass growth averages for Douglas-fir and western hemlock over the six lift/store treatments.

Storage tended to stimulate relatively more allocation to the shoot for both species in either the March 15 or May 15 planting dates. Species responded differently in the sense that western hemlock tended to be relatively more root-oriented in its partitioning than Douglas-fir for any lift/store combination. This may be a reflection of western hemlock's tendency to be a moisture stress avoider and Douglas-fir's tendency to be a moisture stress tolerator.

Western hemlock also favored the root over the shoot for the March 15, no storage and for the May 15 stored and non-stored regimes. Douglas-fir had root dominant partitioning for the March and May 15 lifts, no storage, and the March 15 lift with two months storage. The strongest shoot partitioning for Douglas-fir was for the January 15 lift, four months storage; for western hemlock, it was for the January 15 lift, no storage.

The most marked example of the differences in biomass partitioning between species was the latest planting date where, with stock stored for four months, Douglas-fir allocated about 58 percent and western hemlock about 48 percent of their total biomass growth above ground. Non-stored Douglas-fir and western hemlock, for the same planting date, allocated approximately 45 and 38 percent respectively of their biomass growth above ground.

The combination of total biomass production and allocation strategies for species and lift/store regimes correspond well with both relative volume growth and changes evident in dormancy intensity, and frost hardiness with lift/store combinations. It appears that maintenance of a relatively high level of dormancy and frost hardiness may lead to less need for damage repair following outplanting, and more in-phase development of root and shoot over the growing season.

Seedlings able to put out roots during the first part of the growing season likely experience reduced seasonal moisture stress. Higher stress resistance, less stressful post-plant conditions, and a longer growing season, led to greater total biomass growth and a larger proportion of that biomass allocated to the shoot. This resulted in shorter, fatter seedlings than those which began the season with a heavier stress load, lower stress resistance, rapid budburst, and relatively little root production.

PREDICTION OF VOLUME GROWTH

Relative volume growth was significantly correlated with dormancy intensity (r^2=0.628) (Figure 12). RGC, electrolyte leakage, and foliage browning were less well correlated (r^2= 0.375, 0.358 and 0.269 respectively). Relative volume growth tended to decrease as dormancy intensity decreased, as electrolyte leakage and foliage browning increased, and as RGC increased.

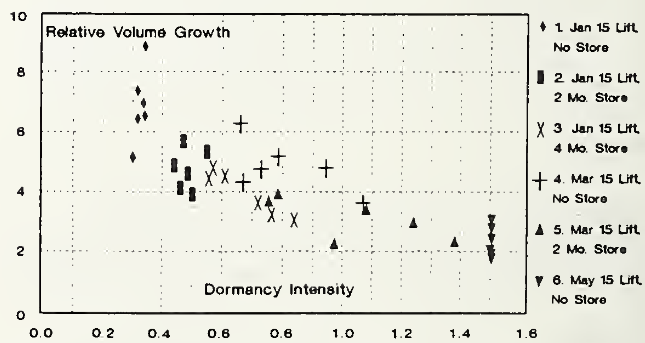

Figure 12.--Relationship between relative volume growth and dormancy intensity for Douglas-fir and western hemlock over the six lift/store treatments (points are species/stocktype averages).

It is evident that maintaining dormancy intensity in the 0.3 to 0.5 range will tend to maximize relative volume growth. This type of target would infer an electrolyte leakage (-18 C) target of less than 10, a foliage browning (-18 C) target of less than 30 percent, and an RGC target of 3.0 to 3.5.

In general, for any planting dates beyond January 15, early lifts and long storage periods maximize volume growth. The optimum lift/store regimes for both species were the January 15 lift and plant, and the January 15 lift with two months storage.

Earlier planting dates optimize stress resistance with the least stressful environmental conditions following planting. Root and shoot phenology are sufficiently "in-phase" to allow the greatest degree of drought avoidance during the first growing season. Volume growth increases as more photosynthate is produced and as less of that photosynthate is allocated to the roots or to repairing cellular damage.

CONCLUSIONS AND RECOMMENDATIONS

This preliminary investigation of the impact of lift and store regimes on the field performance of containerized Douglas-fir and western hemlock has indicated the following:

1. Lift date and storage duration can significantly effect seedling growth and the pattern of biomass allocation.
2. Early planting dates have the highest volume growth.
3. Cold storage maximized volume growth for both the March 15 and May 15 planting dates for both species.
4. Cold storage delayed the release from dormancy and the loss of frost hardiness relative to non-stored seedlings.
5. The best predictors of volume growth were dormancy intensity and the frost hardiness index (electrolyte leakage).

These results suggest that the following would be reasonable practices for nursery growers and seedling consumers to follow:

1. Douglas-fir and western hemlock should be lifted prior to January 15.
2. Cold storage should be used to minimize the rate of loss of dormancy and cold hardiness.
3. Planting should be done as soon as possible after lifting.
4. Targets for defining high quality stock would be:

   - dormancy release index of 0.3-0.5
   - frost hardiness (-18 C); index of injury <10 and foliage browning <30%
   - RGC >3.0.

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Auger Hole Shape, Size, and Tree Placement Affect Survival and Root Form of Planted Ponderosa Pine in South Central Idaho[1]

John Sloan[2]

Abstract.-- Ponderosa pine seedlings (2-0) were planted in 4- and 6-inch cylindrical auger holes and in 8-inch holes tapering to 4 inches at the bottom. Fifth-year mean survival of trees planted in the tapered holes was higher than three of four other treatments. The size of the planting hole as well as tree placement in the center or on the side of the hole did not affect survival. Mean seedling height after five growing seasons was unaffected by planting hole size, shape, or tree placement. Planting hole shape and tree placement impacted root system form while planting hole size did not.

INTRODUCTION

A tree depends on an adequate root system for acquisition of moisture and nutrients as well as for physical support. After establishment, planted ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) seedlings often have root morphologies drastically different from those grown from seed in place. Soil characteristics, nursery cultural practices, and planting methods of bareroot stock can all have a great influence on the form a root system may take. Root system parameters -- affected by various cultural and planting practices -- include symmetry, balance, constriction, coiling, and taproot development. Trees seeded in place tend to be strongly taprooted in comparison to artificially regenerated trees, which have more of a thick branched root system (Long 1978), and bareroot seedlings have fewer laterals than naturals (Stein 1978). Differences in planting tool, initial size of seedlings, and microsite have also been suggested as possible sources of variation on root system form and tree performance (Lyon 1971, Sutton 1969, Little and Somes 1964, and Rudolf 1950).

Bareroot planting stock with large root systems is especially susceptible to root deformations such as a bent or J-rooted tap root (Stein 1978). A larger sized planting hole may help the planter to keep the roots straight and vertical. Also, the planting hole shape or tree placement within the hole can effect root system form. The important question is, can planting hole size, shape, and tree placement impact the root system enough to also affect the seedling survival and growth?

The standard U.S.D.A. Forest Service practice in the Intermountain Region is to plant a tree in the center of a 4-inch straight-sided hole, augured to a depth sufficient to accommodate the full length of the seedling's root system. In this study we varied the planting hole size, shape, and the placement of the tree to observe the effects on bareroot ponderosa pine seedling survival and growth. The objectives of the study were:

1. To determine if tree survival and growth is greater in 6-inch auger holes than in 4-inch holes.

2. To determine if survival and growth differ between side-hole and center-hole planted trees.

3. To determine if a beveled planting hole results in better tree survival and growth than straight-sided holes.

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[1] Paper presented at the Western Forest Nursery Council Conference. (Vernon, B.C., August 9-11, 1988).

[2] John Sloan is Forester at the Intermountain Research Station, Forest Service, U.S. Department of Agriculture, ~~at the~~ Forestry Sciences Laboratory, Boise, Idaho.

METHODS

The study was installed on the Mountain Home Ranger District of the Boise National Forest. In mid May 1983, bareroot 2-0 ponderosa pine seedlings were planted on a Pseudotsuga menziesii/Carex geyeri habitat type (PSME/CAGE; Douglas-fir/Elksedge) (Steele and others 1981) at about 4,900 ft of elevation. The soil is a clay-loam of basaltic origin. The site has an easterly aspect and a slope of 10 to 20 percent. Seedling root systems were 12 inches in length. Experienced planters planted the trees in the middle of 2- by 2-ft hand scalps.

Planting holes were drilled using one of three auger bits. Two of them made cylindrical holes with 4- and 6- inch diameters. The third bit tapered from 8 inches at the top to 4 inches at the bottom and was developed at Lucky Peak Nursery near Boise, ID. Figure 1 explains the five treatments which were randomly arranged in each of 10 blocks.

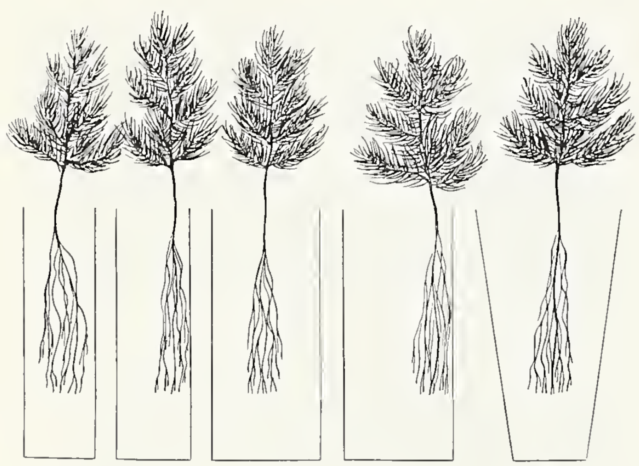

Figure 1.--Five planting hole configurations: (A) 4-inch straight-sided with tree placement in the center, (B) 4-inch straight-sided hole with tree placement on the side, (C) 6-inch straight-sided hole with tree placement in the center, (D) 6-inch straight-sided hole with tree placement on the side, and (E) 8-inch hole tapering to 4 inches at the bottom, with tree placement in the center.

Each treatment consisted of a row of 10-trees. Planting spots were 6 feet apart between rows and within rows, and planting holes were augered to a 14-inch depth. The times required to auger and plant each row were recorded during plot establishment. Survival and total height of each tree were measured after planting and then after the first, second, third, and fifth growing seasons. Finally, after 5 years of growth, several trees from each treatment were excavated to examine the root systems.

RESULTS AND DISCUSSION

Mean fifth-year survival of seedlings planted in the tapered holes was higher (α = .05) than in the 4-inch hole with side placement, the 6-inch hole with the side placement, and the 6-inch hole with center placement (table 1 and fig. 2). Survival of the seedlings planted in the 4-inch hole with center placement was intermediate. After five growing seasons, mean heights are close for all five treatments (table 1).

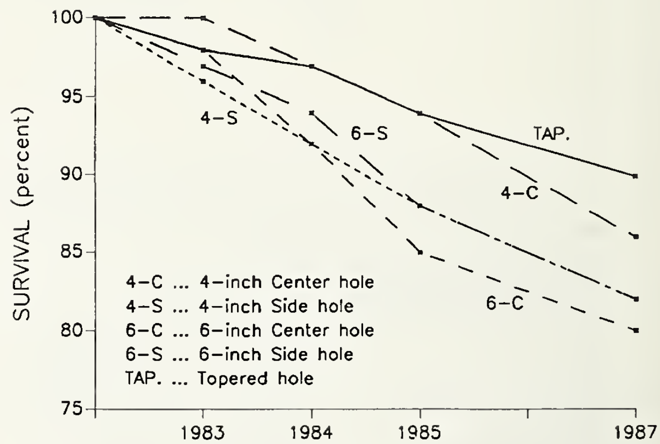

Figure 2.--Five-year survival of ponderosa pine seedlings in planting holes of different configuration. Based on first, second, third, and fifth year measurements.

These results are comparable to Buchanan's (1974) study in which after two growing seasons he found no difference in survival between ponderosa pine planted in the center of the hole and planted on the side of the hole. Little and Somes (1964) saw that center-hole planting of southern pines resulted in more spreading root systems than did slit planting. However, they still frequently found the roots of the center-hole seedlings to be in a single plane, and often the taproots were deformed.

After five growing seasons since planting, the shapes of the root systems tended to be similar within each treatment but varied between treatments. Generally, we found the straightest taproots on the trees that were

Table 1.--Mean auger and planting times per 10-tree row and fifth-year seedling mean heights and survival. Values followed by the same letter are not significantly different at the 95 percent level of confidence

Auger hole sizes (inches)	Tree placement	Augering time (sec)	Planting time (sec)	5th year height (cm)	5th year survival (percent)
4	Centerhole	45.6 a	195.1 b	57.3	86 ab
4	Sidehole	45.2 a	154.9 a	57.7	82 a
6	Centerhole	87.7 b	255.3 d	59.3	80 a
6	Sidehole	96.0 bc	191.5 b	57.0	82 a
4 - 8	Centerhole	81.8 b	232.2 c	62.2	90 b

planted on the side of the planting hole (fig. 3). However, the root systems of the side-hole trees have tended to remain in a single plane. The center-hole planted trees had root systems that spread more in all directions, but most had a slight bend in the taproot (fig. 4).

Overall, the trees planted in the tapered holes produced a spreading bell-shaped root system (fig. 4) with the most laterals of any treatment, but it is still much different from that of a seeded-in-place tree. The center-placed root systems in the straight-sided holes were also bell shaped, but most of the roots were directed downward. The planting hole size did not seem to affect the root system size, shape, or symmetry.

How these initial differences in root system morphologies will influence future growth and survival of the stand is unclear. However, none of these deformations are considered serious. I expect normal tree growth and development.

Several investigators have studied root deformations. Greene (1978) found that once established, root deformities tend to persist, but in time, root systems can partially mend themselves. Chavasse (1978) states that it is difficult to satisfactorily distribute roots during normal planting operations. Eis (1978) reported that the lifetime configuration of a root system is established early, and Long (1978) found that differences due to cultural practices were evident after 4 to 7 years. In contrast, Van Eerden (1982) reported that some deformed root systems repair themselves in time and increasingly acquire a normal or natural growth habit. According to Bibelriether (1966), this takes about 30 to 40 years. While Long (1978) found a weak correlation between root system deformation and tree growth, others found little evidence to connect them.

The 4-inch planting hole took less time to auger than the other holes (table 1). The 6-inch holes took twice as long as the 4-inch holes to auger. Tapered holes were slightly faster than the 6-inch holes. Side-hole planting went faster than center-hole planting and the 4-inch holes took less time to plant than the 6-inch and tapered holes.

Total planting time consisted of the time it takes to auger the hole plus the time to plant the tree. Of the five treatments, the 4-inch hole with the tree placed on the side was the fastest (fig. 5). The next fastest treatment was the 4-inch hole with center placement. Planting times for the center-placed trees in the 4-inch hole and the side hole placement in the 6-inch holes were very close, but because augering of the 6-inch hole took longer, total time was shorter for the 4-inch center treatment. Finally, the 8-inch hole, tapering to 4 inches, had a total planting time that was only less than the treatment with a 6-inch hole and center placement of the tree.

SUMMARY

Of the five treatments studied, the seedlings planted in the tapered holes survived best. Neither the size or shape of the planting hole, nor the tree placement influenced height growth in the first five growing seasons.

Side-hole placement tended to cause a flattened root system on one side, but all had straight tap roots after five growing seasons.

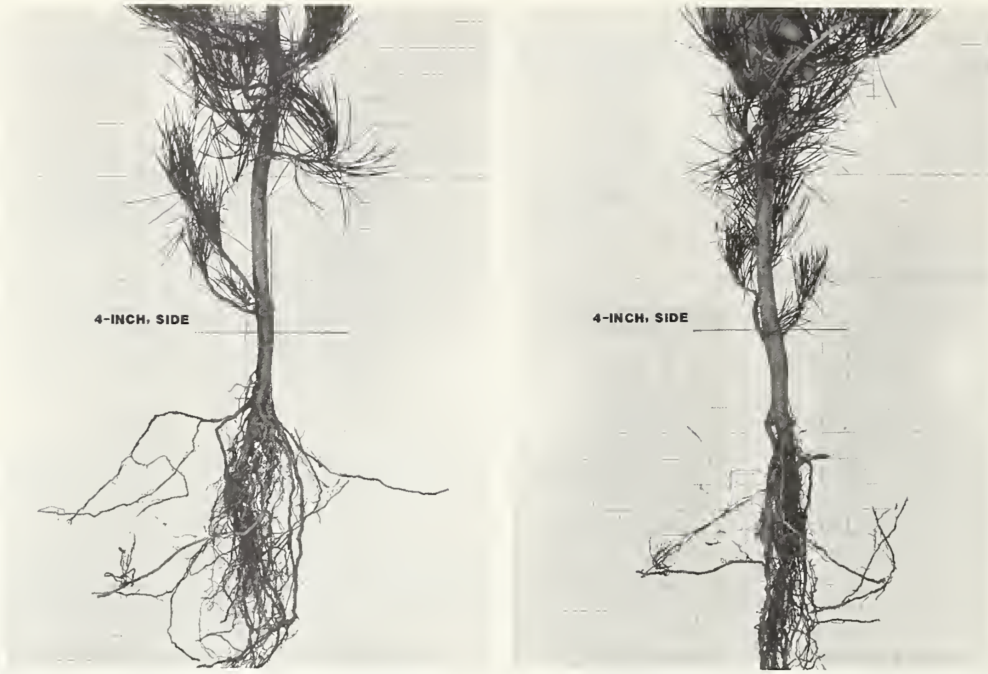

Figure 3.--A representative seedling root system that was excavated after five growing seasons. The two photos are of the same tree that was planted in the side-hole fashion. The root system in the second photo is rotated 90 degrees from the first and illustrates the somewhat flattened configuration of side-hole planted trees.

Figure 4.--These are representative seedling root systems that were excavated after five growing seasons. All three trees were planted in the center of the planting hole. The root system on the left came from a 4-inch hole, the one in the center came from a 6-inch hole, and the seedling on the right was planted in a 4- to 8-inch tapered hole.

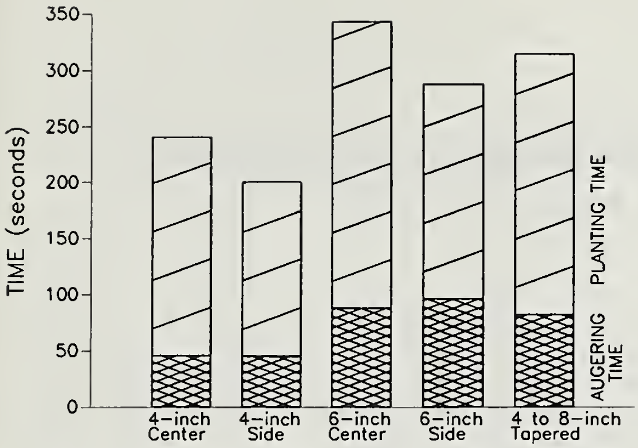

Figure 5.--Planting times required to drill holes and plant ponderosa pine seedlings in 4-, 6-, or 4- to 8-inch holes with tree placement either in the center or on the side.

Seedlings planted in the center of the hole often still had a bend in their taproot 5 years after planting. Overall, trees in tapered planting holes had the most spreading root systems. Seedlings in the center of straight-sided holes had the most fibrous root systems, but most of them were directed downward. Differences in root form are not expected to affect future height growth.

Large planting holes took longer to auger. Seedling placement on the side of the planting hole was quicker than planting in the center.

Applicablity of the results presented here may vary depending on the size of the planting stock, site quality, and especially soil type.

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Field Measurement of Photosynthetically Active Radiation[1]

D.A. Draper,[2] D.L. Spittlehouse,[2] W.D. Binder,[2] and T. Letchford[3]

Abstract.--Site preparation treatments reducing competing vegetation achieved adequate light levels for white spruce photosynthesis but did not alleviate limiting root zone soil temperature. Mechanical treatments which disturb site humus layers increased both light availability and soil temperature and resulted in increased growth performance over a 5 year period. Increased depth of mineral capping on inverted organic mounds significantly increased seedling growth performance.

INTRODUCTION

Intensity of radiation exerts a direct effect upon plant photosynthesis and morphogenesis, and an indirect effect due to environmental heating. In selecting site preparation treatments it is important to identify factors limiting growth on the site (Cleary and Kelpsas 1981, Draper 1982), and to assess the extent to which the treatment has been successful in reducing these biological stresses. On sites with well developed competitive vegetation, the relative importance of increased radiation to the seedling for driving the light reaction in photosynthesis, and the role of radiation in increased environmental heating, following a site preparation treatment, is often unclear. Field investigations are seldom able to separate the combined effect of most site preparation treatments. However, an understanding of this is important in developing and selecting treatments which promote seedling survival and growth in the regeneration time frame.

In this study the direct effects of site preparation treatment on photosynthetically active radiation ([PAR], 400 - 700 nm wavelengths) at seedling height was measured for two growing seasons following treatment, and interpreted in terms of light compensation and saturation thresholds determined for spruce (Picea glauca (Moench) Voss) seedlings in the field. Subsequent five year seedling height and ground-line diameter growth data are also presented for these treatments. The short term response of radiation and soil temperature to serial vegetation clipping, and combined vegetation and organic layer removal to mineral soil, are presented for the same site. Comparative soil temperature data from a wide range of site preparation strategies on adjacent sites are presented as well.

SITE DESCRIPTION

A north-east aspect, slope of the Bowron River Valley (Lat. 53° 40' N, Long. 121° 40' W) in the central interior of British Columbia was selected for study. The site is within the Rocky Mountain Subzone (f) of the sub boreal spruce zone[4]. Prior to treatment, abundant herb and brush species (0.85 - 1.20 m average height) combined to present severe vegetation competition. Soils on the site are gleyed, grey luvisols (Can. Soil Survey Com. 1978) characterized by mottling. The area's continental climate (mean January and July air temperatures -12 and 15° C, respectively) and site history under a 200-300 year-old mature spruce and alpine fir forest canopy, have resulted in development of a thick (0.10 - 0.25 m) mor humus layer. This organic layer remained largely undisturbed following winter logging in 1982.

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[1] Poster presented at the Combined Western Forest Nursery Council, Forest Nursery Association of B.C. and Intermountain Forest Nursery Association meeting; 1988 August 8-11; Vernon, B.C.

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SITE PREPARATION AND PLANTING

A Bräcke cultivator equipped with Robur Maskin A-B's Högläggare mounding attachment behind a D7E prime mover was used to create inverted organic mats in August 1983. The mounder shovels were disengaged throughout, resulting in inversion of 0.3 by 0.4 m patches of consolidated organic material over undisturbed organic material. Manual additions of 0.0, 0.06, 0.12 and 0.24 m depth cappings of B horizon mineral soil were carried out to create a depth of capping range referred to as the organic mat and mineral mound treatments, respectively. Control (not mechanically prepared) areas were also established as part of the trial design. Bare root 2+1 white spruce (B.C. Forest Service Registered Seedlot 4093) were planted on all site preparation treatments between May 30 and June 15, 1984. Seedlings were centered on prepared organic mats and mounds, and planted within a screef to mineral soil on the control treatment.

A wide range of site preparation treatments were established on adjacent areas for further comparison. These were an operational prescribed fire treatment (burned August 1983); a broadcast herbicide application (0.8 m radius plot, Roundup [glyphosate] at 2.25 kg a.i.$\cdot$ha^{-1} on August 5, 1983); a blade scarification treatment (organic layers scalped to bare mineral soil on August 1983); and, broadcast herbicide treatment combined with inverted organic, mineral mounds (0.30 m depth of capping on inverted organic patches in August 1983).

MEASUREMENTS

Measurements were made of diurnal PAR patterns on 5 replicates of seedling pairs (control and 0.24 m mound treatment, 1984) and triplets (control, organic mat, and 0.24 m mounds, 1985) using Li-Cor 190SB cosine corrected quantum sensors, interrogated every 60 seconds and integrated and recorded every 30 minutes. Treatment sensors were levelled at predetermined mean seedling height of 0.36 m (1984) and 0.44 m (1985), while a background sensor was maintained above competing vegetation (1.5 m). The replicate pairs or triplets were sampled sequentially (between July 18 and October 16, 1984, and June 9 and September 17, 1985) in 14-21 day cycles to provide treatment averages. Background and treatment sensor readings were made simultaneously and recorded in μE m^{-2} s^{-1}. For comparative purposes, treatment values may be expressed as a percent of background PAR rate or as mean daily radiation totals (μE m^{-2} day^{-1}). Generalized light saturation and light compensation thresholds (600 and 100 μE m^{-2} s^{-1}, respectively) were determined for these white spruce seedlings in the field using a Li-6000 portable photosynthesis apparatus (Draper et al. 1985). Mean seedling height and ground-line diameter were measured at time of planting and at the end of the first through fifth growing seasons on all treatments.

A single, 1.26 m radius, clipping plot was established in a representative complex of lady fern, fireweed and false hellebore (0.90 m height) and instrumented with 3 replicated thermistor-type soil temperature sensors (0.05 m depth in mineral soil), and a quantum sensor leveled at 0.15 m at plot centre. In an immediately adjacent area, left untreated, a further 3 soil temperature sensors and a background (1.5 m) PAR sensor were installed. Daily mean, minimum and maximum soil temperatures were calculated from 30 minute averages and recorded. Plot vegetation was serially clipped and removed on August 15, 19, 22 and 27 reducing plot leaf area from 100% to 0%. Clipped leaf area was measured with a Li-Cor 3100 leaf area meter and expressed as a percentage of total plot leaf area. Following removal of all competing vegetation the plot was manually scalped on September 8, to bare the mineral soil surface.

A series of soil temperature sensors were installed in alternative site preparation treatments on site including a control treatment, prescribed fire, blade scarification, organic mat inversion (Bräcke patch scarification), mounding treatments with differing levels of capping, broadcast herbicide treatment, and broadcast herbicide in combination with mounding. A manual (1200 - 1400 h) measurement was made of 4 replicate thermistors in the 1985 growing season, and, for comparative purposes the data expressed as a percentage of the measured control treatment temperature.

RESULTS

Figure 1 shows a typical diurnal PAR trace on a clear July day as received above the vegetation (background), and at seedling height in the control and mounded treatments. The mineral mound treatment received nearly all measured background radiation with the exception of low sun-angle periods (0500-0900 and 1700-2100 h PDST). The control treatment trace is strongly affected by vegetation interception, resulting in an irregular sun-fleck pattern over most of the lighted part of the day. Rate of PAR on the mound treatment is nearly that of background at mid-day, but control PAR rate is much reduced compared to background.

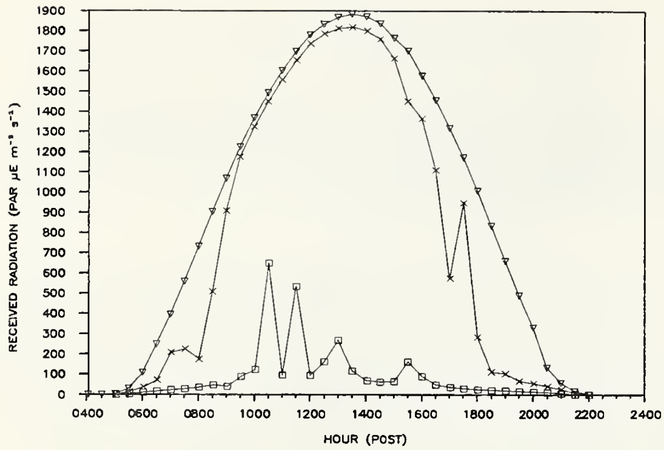

Figure 1.--Typical diurnal PAR pattern on a clear July day in 1984 one year after site preparation. Background sensor above competing vegetation (▽) at 1.5 m height, control (□) and mineral mound treatment (x) sensors at seedling height (0.36 m).

Daily treatment PAR patterns, averaged over the 1984 growing season, are shown in Figure 2 with light compensation and saturation thresholds overlain. Values plotted are the mean half hourly rate of replicated samples between July 18 and October 16, 1984. One year following site preparation, mounded seedlings received approximately 70% of mean total daily radiation (background). The control seedlings averaged 11% of background over the same period. Interpreted in terms of the light thresholds, mounded seedlings received 66% of available PAR between 100 and 600 $\mu E\ m^{-2}\ s^{-1}$ and were above compensation threshold for 10-11 hours a day. Control seedlings, by contrast, averaged 15% of background total radiation between 100 and 600 $\mu E\ m^{-2}\ s^{-1}$, and exceeded compensation thresholds for only 4-5 hours in the average day (fig. 2).

In the second growing season (1985) a combination of increased mean seedling height and a reduction in average height of competing vegetation changed the relationship of received radiation between treatments. Control, organic mat and mound treatments seasonal mean diurnal patterns are given in Figure 3. Mound treatments received 78%, the organic mat treatment 64% and the control 49% of mean daily background total PAR. Duration of exposure to PAR above compensation threshold was similar for all treatments, averaging 10-11 hours a day. Seedlings planted on organic mats received less total radiation than mounded seedlings, but similar amounts between the 100 and 600 $\mu E\ m^{-2}\ s^{-1}$ thresholds.

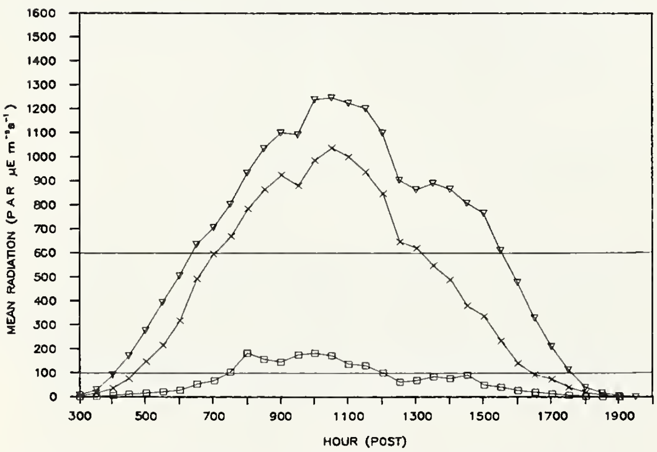

Figure 2.--Treatment mean diurnal PAR pattern during 1984 (July 18-Oct.16) growing season. Background sensor above competing vegetation (▽) at 1.5 m, control (□) and mineral mound treatment (x) sensors at seedling height (0.36 m). 100 and 600 $\mu E\ m^{-2}\ s^{-1}$ light compensation and saturation thresholds, respectively.

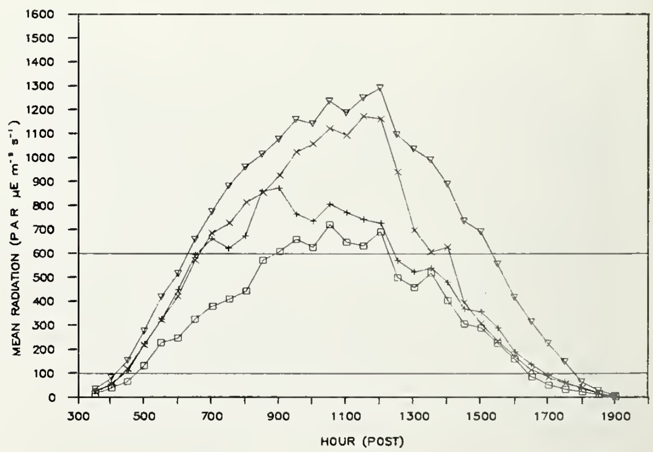

Figure 3.--Treatment mean diurnal PAR pattern during 1985 (June 9-Sept.17) growing season. Background sensor above competing vegetation (▽) at 1.5 m, control (□), inverted organic mat (+) and mineral mound treatment (x) sensors at seedling height (0.44 m). 100 and 600 $\mu E\ m^{-2}\ s^{-1}$ light compensation and saturation thresholds, respectively.

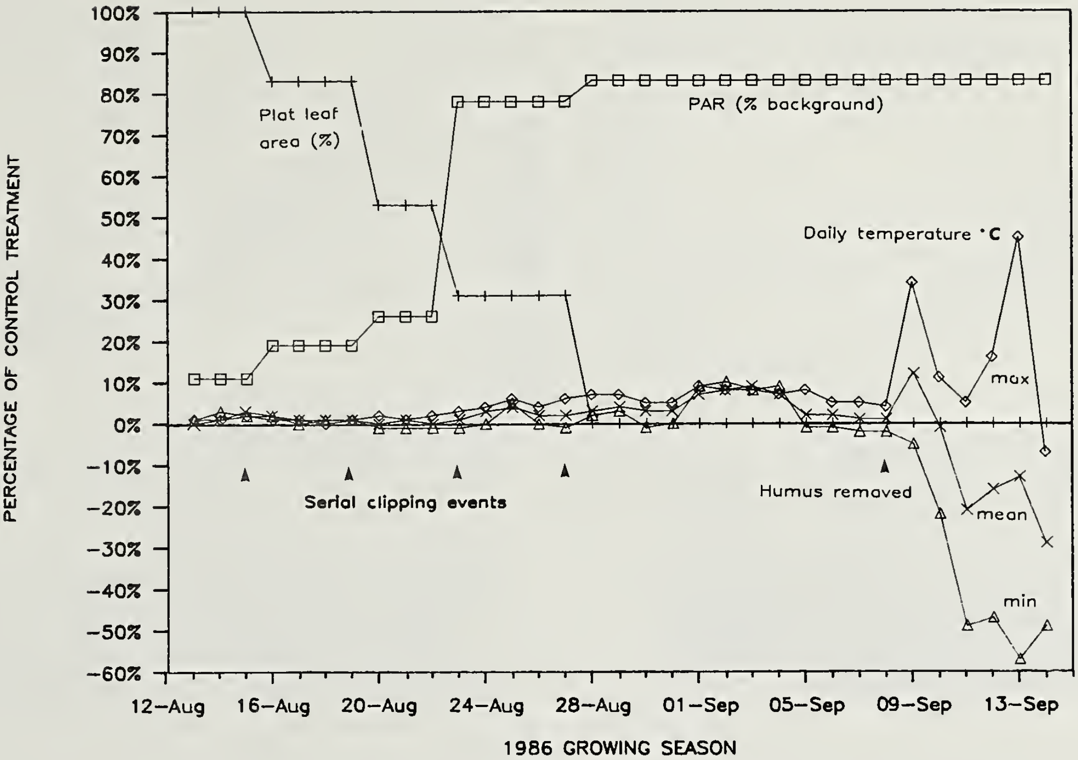

Figure 4.--Short term response of received radiation at seedling height and soil temperature (0.05 m depth) to reductions in vegetative cover. Seedling radiation (□) expressed as a % of background (1.5 m) radiation, and daily minimum (△), maximum (◇) and mean (X) mineral soil temperature (0.05 m depth) as a % of control (untreated) soil temperature. Leaf area reductions (+) on August 15, 19, 22, 27 expressed as a % of plot total leaf area.

The effect of incoming PAR on short term soil temperature characteristics was assessed by serially reducing the vegetative cover of a 1.26 m radius plot and measuring changes in received PAR and soil temperature (fig. 4). Prior to first treatment (August 15) radiation beneath the undisturbed competing vegetation canopy averaged 11% of background daily totals. In the same period, daily soil temperature averages in the treatment plot exceeded those of the adjacent control by about 1%, or 0.1° C above the control average of 10° C. PAR response to vegetation removal, averaged over the post clipping period, was immediate (fig. 4). Removal of up to 50% plot leaf area increased received radiation at 0.15 m height from an average of 11% to only 26% of background. The next vegetation removal, from 50% to 30% plot leaf area, resulted in a large increase in received PAR from 26% to 80%. Subsequent removal of the remaining 20% plot leaf area had little effect on received radiation percent (fig. 4). The difference between plot PAR after August 28 (100% leaf area removed) and background PAR is attributed to plot edge effects at low sun angles (see fig.2 and 3).

Daily soil temperature at 0.05 m depth in the mineral soil, beneath a 0.20 m consolidated mor humus, did not respond greatly to level of vegetation clipping, or total vegetation removal (fig. 4) over the period considered. Effects have not been masked by considering average daily mean, minimums and maximums as the half hourly trends collected (not presented) did not show a consistent response to clipping treatments either. Maximum increases in mean daily soil temperature over the 12 day period following vegetation removal were 9%, or less than 1° C, greater than the 10° C control soil temperature recorded (fig. 4), and followed a 4 day period of high radiation.

Scalping the organic layer to expose mineral soil (September 8) had an immediate and relatively large effect on soil temperature (fig.4). Daily mean, maximum and minimum temperatures were directly driven by ambient air temperature (not shown). Scalped plot maximum daily temperatures exceeded control maximums (7.5° C) by 3° C, and minimum temperatures were as much as 4° C below the recorded control daily minimum of 6.5° C.

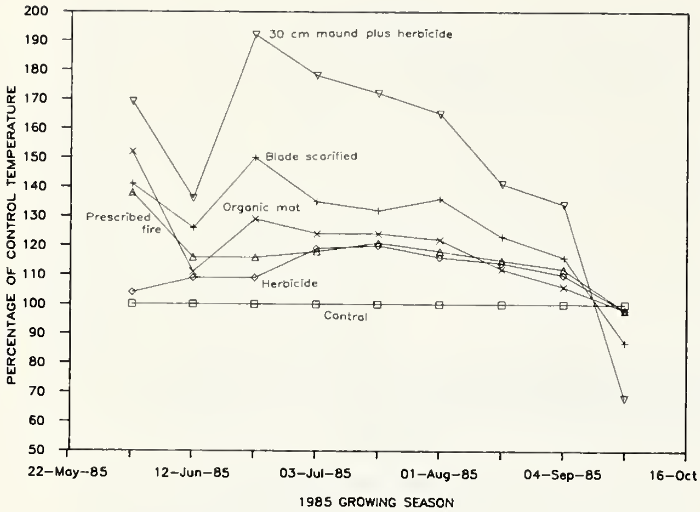

Figure 5.--Mean mineral soil temperature (0.10 m depth) between 1200-1400 h PDST by site preparation treatment over the 1985 growing season. Values expressed as a % of control (untreated) soil temperatures.

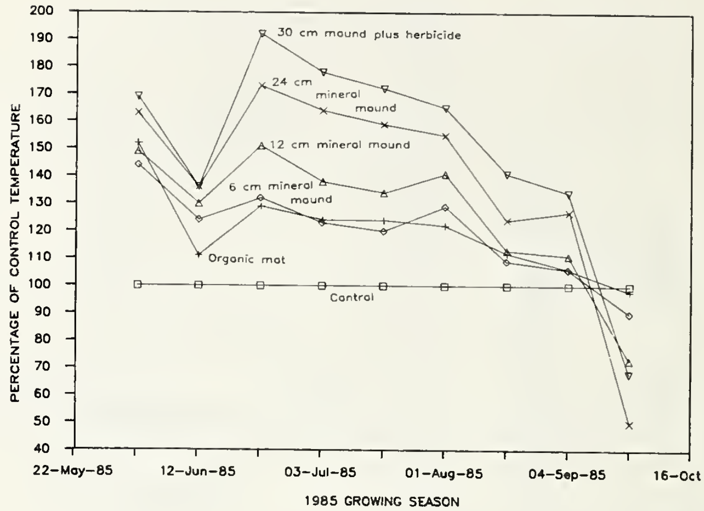

Figure 6.--Mean mineral soil temperature (0.10 m depth) between 1200-1400 h PDST by site preparation treatment over the 1985 growing season. Values are expressed as a % of control (untreated) soil temperatures.

Data presented in Figure 4 is corroborated by the general temperature response measured over a wide range of site preparation treatments. Highest mid-day mineral soil temperatures (0.10 m depth) were recorded on site preparation treatments which remove or invert the organic layer (fig. 5). Neither prescribed fire treatment (which blackened and reduced but did not totally consume the organic layer), or the herbicide treatment (which effectively controlled competing vegetation to less than 30% total cover) were as effective at increasing mid-day soil temperatures as mechanical treatments. Within the range of inverted organic mat and mounding treatments tested (fig. 6) there was a consistent increase in soil temperature associated with increased depth of mineral capping. Seasonal average control temperatures in Figure 6 ranged from 6° C in late May to 10° C in August. Large mineral mound soil mid-day temperature averaged 15° C over the same period. Reduction of the vegetative competition remaining after mounding by herbicide application further increased measured soil temperature as shown by the mounding plus herbicide treatment (fig. 6).

Increased depth of mineral capping on inverted organic mats resulted in increased soil temperatures and subsequent improvement in seedling growth (figs. 7 and 8). The trend to increased total height and ground line diameter with increased depth of mineral capping is consistant, and the fifth year treatment means are significantly different statistically. This corroborates observations made by McMinn[5] regarding growth performance of spruce seedlings on inverted organic mounds with differing levels of capping.

DISCUSSION

On sites with continuous, well developed organic layers site preparation should be targeted at reduction, mixing or inversion of the organic material to increase root zone soil temperatures rather than vegetation reduction to increase available light. Mechanical treatments which remove or disturb the insulating organic layers are associated both with increases in soil temperature (McMinn 1982) and adequate PAR for photosynthesis (fig. 3). Removal of vegetation alone, on sites with relatively thin humus, may result in increased soil temperature[6], but more generally, soil temperatures in the sub boreal spruce zone are too low for maximum root growth even following clear cutting (Dobbs and McMinn 1977, Draper et al. 1985).

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[5] McMinn, R.G. Personal conversation, August 1985. Research Consultant, Victoria, B.C., Canada.

[6] Coates, D.K. 1987. Effects of shrubs and herbs on conifer regeneration and microclimate in the Rhododendron-Vaccinium-Menziesia community of south-central British Columbia. M.Sc. Thesis, O.S.U., Corvallis, WA. Dec. 1987.

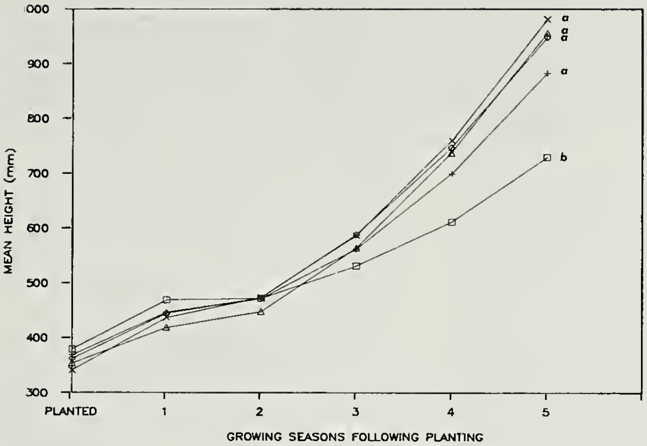

Figure 7.--Treatment mean seedling height (m) at time of planting and following 1 - 5 field growing seasons. Values plotted are the means of approximately 135 seedlings. Control (□), inverted organic mat (mat) (+), mat plus 6 cm mineral capping (◇), mat plus 12 cm mineral capping (△), organic mat plus 24 cm mineral capping (X). Fifth year treatment values followed by the same letter are not significantly different by Duncans multiple range test at alpha = 0.05.

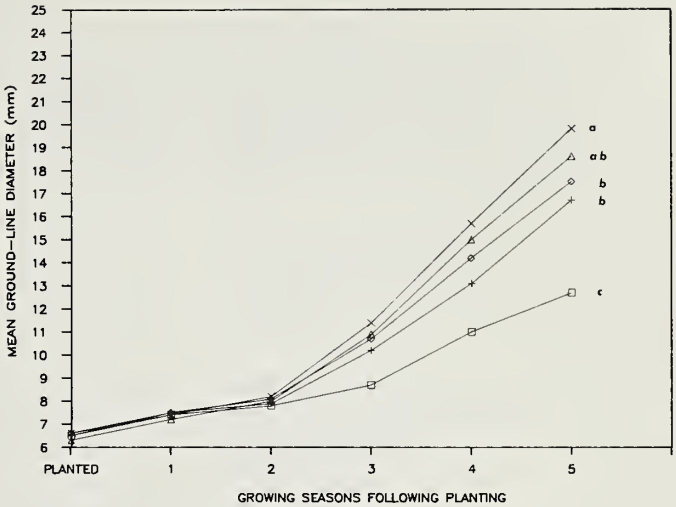

Figure 8.--Treatment mean seedling ground-line diameter (mm) at time of planting and following 1 - 5 field growing seasons. Values plotted are the means of approximately 135 seedlings. Legend as in fig. 7. Fifth year treatment values followed by the same letter are not significantly different by Duncans multiple range test at alpha = 0.05.

Removal of half the leaf area of a 100% cover lady fern association increased received radiation at seedling level from 11% to only 25% of the above canopy background. Significant radiation increases, to well over seedling saturation thresholds, were measured with removal of about 70% of plot leaf area. The advantages of further vegetation reduction are slight in terms of radiation required to drive photosynthesis and measured increased mineral soil temperature (fig. 4) unless the in situ humus is disturbed.

CONCLUSIONS

Identification of the specific biological limitations to seedling growth under field conditions is very difficult, both empirically and experimentally. The relationships of measured light and soil temperature availability to planted seedlings, in response to site preparation strategies, suggest that soil temperatures rather than available light is limiting in the area of the sub boreal spruce zone considered in this experiment. Operational site preparation treatments targeted on organic layer removal or inversion provide both increased soil temperature and, at least temporarily, reductions in competitive vegetation, which result in above average fifth year seedling growth.

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Coast Agri
464 Riverside Rd. S. RR2
Abbotsford, B.C. V2S 4N2

WICKENS, FRED
Fisons
12633 - 26 Avenue
Surrey, B.C. V4A 2K8

WIEGAND, MILES
Rt. 2 3150 Twilight Lane
Moose Lake,
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WIGGINS, GREG
B.C. Research Corp.
3650 Wesbrook Mall
Vancouver, B.c. V6S 2L2

WILKINSON, SHERYL J.
J. Herbert Stone Nursery
2606 Old Stage Road
Central Point, OR 97502

WILLCOCK, DAVID
915 - 23rd S.E.
Calgary, Alta.
T2G 1P1

WILLIAMS, W.C. BILL
2640 Moss Aveue
Prince George, B.C.
V2L 5J3

WILLINGDON, TONY
B.C. Forest Service
3605 - 192 Street
Surrey, B.C. V3S 4N8

WOOD BARRY
Box 750
Smoky Lake,
Alberta TOA 3CO

WOOD,TERRY
Westgro Sales Inc.
13880 Vulcan Way
Richmond, B.C. V6V 1K6

WOOD, SCOTT
Ropak Capilano Ltd.
1081 Aiveden Avenue
New Westinster, B.C

WOODS, JACK
B.C. Forest Service
Box 335
Mesachie Lake, B.C. VOR 2NO

YOSHIZAWA, WAYNE
Ki International
5413 Rawlands Crescent
Delta, B.C. V4M 1J2

ZEDEL, SUSAN
896 Verdier Avenue
Brentwood Bay, B.C.
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ZHANG, SONGDAN, MR.
People Republic
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ZIELKE, KEN
Selkirk College
Box 1200
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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526